The Role of Socio-Cognitive Process in Construction Workers' Safety Behaviors

by

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DEDICATION

To my wife Yoonjung and little baby Soobin

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ABSTRACT

Despite continuous efforts to reduce its number of accidents, construction still remains one of the most hazardous industries in most countries. The vast majority of accidents in construction are associated with workers' unsafe behaviors. As a result, researchers and practitioners have devoted considerable effort to investigating various approaches to reduce workers' unsafe behaviors. Still, a noticeable lack of research and practices investigating how workers' cognitive processes and their interactions with the environment (e.g., coworkers, managers, and site risk) affect safety behaviors persists. With this background in mind, three broad objectives have been established in this research: (1) to identify the mechanism of social influence on workers' safety behavior, (2) to characterize how workers' decision-making processes and the environmental factors interact to affect safety behaviors, (3) to develop research methods to overcome the limitations in previous worker behavior studies. To achieve these research objectives, five interrelated and interdisciplinary studies such as survey analyses, behavioral economic experiments, agent-based modeling and simulation of human behavior, field experiments, and physiological sensor data analysis were conducted. Through these studies it was found that: (1) safety norms shared by managers are significantly stricter than safety norms shared by workers; (2) workers' safety behaviors are not only influenced by coworkers' safety behaviors (i.e., workgroup norm) but also subject to managers' safety feedback (i.e., management norms); (3) workers' social identification with their project intensifies positive influence of management norms and attenuates negative influence on workgroup norms to improve workers' safety behaviors; (4) project identity is the least salient in construction workers' self-concept among diverse organizations at construction sites (e.g., workgroup, company, union, trade, project); (5) the effects of different safety management strategies (i.e., stricter safety feedback, more frequent safety feedback, and stimulation of project identification) on workers' safety behavior vary based on site risk conditions (low, moderate, high-risk conditions); (6) electrodermal response (EDR) collected from workers' wristband has a great potential to understand risk perception during their ongoing work. These findings identify the socio-cognitive mechanism of workers' safety behaviors and provide insight into how to improve workers' safety behavior and ultimately to reduce accidents in construction by promoting positive social influence regarding safety behaviors.

CHAPTER 1

INTRODUCTION[1]

1.1 BACKGROUND

Despite continuous efforts to reduce the number of accidents, construction still remains one of the most dangerous industries in the U.S. and around the globe (Jebelli et al. 2016). In 2014, for example, the U.S. construction industry reported the largest number of fatalities (N = 894), with a fatal injury rate 2.88 times higher than the average of all industries (US BLS 2016a). Although the construction industry employs 4.1% of the U.S. workforce (US BLS 2015), it accounted for more than 18% of all work-related deaths in 2014 (US BLS 2016a). In 2015, the construction industry reported that a total of 79,840 nonfatal injuries resulted in days away from work. The injury rate was 43.6% higher than the national average rate (US BLS 2016b). It is estimated that fatal and nonfatal injuries at construction sites result in over $15 billion in direct cost (Tixier et al. 2014). Furthermore, the poor safety performance of the construction industry has been a major concern in not only the United States, but also throughout the United Kingdom (Haslam et al. 2005), European Union (Meliá et al. 2008; Törner and Pousette 2009), Asia (Fang et al. 2006), and Australia (Lingard et al. 2010).

Accident investigations have demonstrated that workers' unsafe behavior, which refers to the behavior that deviates from safety work procedure, is one of the main causes of construction accidents. Heinrich et al. (1950) examined 75,000 accident cases and reported that 88% of all industry accidents were caused mainly by human errors. Based on the investigation of occupational

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[1] Part of this chapter is adopted from Choi, B. and Lee, S. (2018) "An Empirically Based Agent-Based Model of the Sociocognitive Process of Construction Workers' Safety Behavior." *Journal of Construction Engineering and Management*, 144(2), 04017102.

fatalities between 1985 and 1990 in Finland, and serious accidents at work in 1988 and 1989, Salminen and Tallberg (1996) found that 84–94% of accidents were primarily caused by unsafe actions of people. Suraji et al. (2001) affirmed this in their study of 500 records of construction accidents in the United Kingdom (UK HSE) (2002) also noted that workers' unsafe behavior is attributable to approximately 80% of accidents in the workplace. Hinze (2006) showed that over 75% accidents in construction were caused by the unsafe behaviors of workers.

Such alarming figures have prompted construction practitioners to pay greater attention to workers' unsafe behaviors. In practice, efforts to reduce workers' unsafe behaviors have mainly relied on external formal controls such as penalties for violations of safety rules (Mitropoulos et al. 2009; Törner and Pousette 2009). These approaches, however, may not be effective in reducing workers' unsafe behaviors because formal rules do not consider the complex and dynamic situations that occur during a given construction operation (Andersen et al. 2015). Work conditions in one project cannot be equated to other projects because every construction project possesses a unique nature with respect to design, location, participants, and so on. Also, progress in a construction project results in dynamic changes in work conditions within the same project. Therefore, it is challenging and impractical to prescribe behavioral safety rules in every possible situation in such complex and dynamic construction operations. In this context, construction workers' safety behavior would be the result of their discretionary decisions rather than their reactions to the external controls. The formal rule enforcement could also cause unexpected adverse effects due to workers' psychological resistance to the management. Given these limitations of external controls, more attention has been paid to the mechanisms of how to shape and change workers' safety behavior.

1.2 SOCIO-COGNITIVE ASPECT OF WORKERS' SAFETY BEHAVIORS

1.2.1 Cognitive Model of Safety Behaviors

Given the importance of workers' behaviors in construction safety, there has been increased interest in the cognitive process of workers' safety behaviors. Such researchers have suggested that workers' unsafe behaviors are the result of human errors in the workplace. The human error refers to "individuals' misjudgment or inappropriate decision in the cognitive process" (Chi et al.

2013). Reason (1990) suggested the Generic Error Modeling System (GEMS) that focuses cognitive factors in human error and proposed three categories of human error: skill-based, rule-based, and knowledge-based error. Rasmussen (1986) proposed the Step Ladder Model (SLM), consisting of eight stages in the decision-making process: “activation, observation, identification, interpretation, evaluation, goal selection, procedure selection, and execution.” Wickens (1984) suggested an information-processing model describing individuals’ cognitive processes when an individual interacts with the outside environment. This model consists of four cognitive stages, “sensory processing, perception, response selection, and response execution,” and three functional modules, “attention resources, working memory, and long-term memory.” Based on the information processing model, workers’ unsafe behaviors are the result of cognitive failures in the cognitive process. In this regard, Jiang et al. (2014) developed a system dynamics model to investigate the causes of construction workers’ unsafe behavior. Also, Fang et al. (2016) proposed a Cognitive Model of Construction Workers’ Unsafe Behaviors (CM-CWUB) that consists of obtaining information, understanding information, perceiving responses, selecting responses, and taking action. Although these different models vary in details, they all emphasize risk perception, risk assessment, and decision making.

The factors of risk perception, risk assessment, and decision making have been included in theoretical models of health behavior such as Health Belief Model (HBM) (Rosenstock 1974) and Protection Motivation Theory (PMT) (Rogers 1975). Considering that individuals’ health behaviors are a proactive action to prevent health risk (e.g., disease), health behavior would be in line with workers’ safety behavior from the perspective of the cognitive process. The HBM, which is widely accepted in public health research, suggested that an individual’s intention to engage in recommended health actions is determined by the combined levels of perceived risk of the disease and perception of benefits and barrier of the recommended actions. In construction safety literature, Weidman et al. (2016) adopted HBM to develop managerial interventions to encourage worker’s adoption of a ventilated dust-control tool that reduces dust exposure in the workplace. Also, PMT posited that an individual’s likelihood of accepting recommended health behavior is influenced by his/her appraisal of health risk and recommended behavior. In this regard, Rodríguez-Garzón et al. (2014) provided empirical evidence on the association between perceived risk and safety training in construction industry based on the PMT.

1.2.2 Social Influence on Safety Behaviors

Since construction workers work in a social context, workers' safety behaviors are not only results of the cognitive process of isolated individuals but also of their interaction with others. In this regard, social aspects of workers' safety behavior also have drawn considerable interests in safety research. Many researchers have shown that workers' safety behaviors are under the influence of social controls such as safety culture, safety climate, and safety norms. Safety climate refers to "employees shared perception of organizational safety policies, procedures, and practices" (Zohar 1980). Results from previous studies have demonstrated a significant association between safety climate and safety behavior (Siu et al. 2004; Seo 2005; Fang et al. 2006; Beus et al. 2010; Fugas et al. 2012). Social norms refer to a shared expectation of what is normal and acceptable behavior in a group (Gundlach et al. 1995). A number of previous studies have noted that workers' safety behaviors are influenced by safety norms (Törner and Pousette 2009; Jiang et al. 2010; Fugas et al. 2011). Since safety climate serves as a frame of reference that guides expected safety behaviors by providing information for behavior-outcome contingencies in an organization (e.g., consequences of working fast but unsafely) (Zohar and Luria 2005), it would play a critical role in forming social norms among the workers. Social norms can be very powerful in regulating workers' safety behavior because they can account for those varied and situational behaviors in which it becomes difficult for a worker to judge the appropriateness of the behavior (Deutsch and Gerard 1955; Barling et al. 2008). Also, since social influence is involved with the process of genuine internalization of social norms rather than superficial compliance, behavioral changes driven by social norms would be more durable and cost-effective than formal controls (Akerlof and Kranton 2000; Hogg and Smith 2007).

The process of behavioral changes driven by social norms can be explained by Social Identity Theory (SIT). Social identity is defined as "the individual's knowledge that he/she belongs to certain social group together with some emotional and value significance to the group membership" (Hogg and Terry 2000). According to the SIT, if a particular group becomes salient in one's self-concept through the social identification process, he/she internalizes of and conforms with the group norms because he/she defines themselves as the exemplar of the group (Terry and Hogg 1996; Bagozzi and Lee 2002; Hogg and Smith 2007). On the other hand, individuals may not be influenced by the group norms if he/she does not identify with the reference group. Based on the SIT, there have been numerous research efforts to understand employees' organizational behaviors (e.g., work satisfaction, motivation, organizational citizenship behavior, and communication) from the perspective of their organizational identification (i.e., employees' social identification with their organization). These studies found that employees' organizational identification is a powerful mechanism that regulates behavior in the organization (Dutton et al. 1994; Riketta 2005; Walumbwa et al. 2008; He and Brown 2013).

1.3 PROBLEM STATEMENTS

Although previous studies have made a significant contribution to our understanding of the socio-cognitive aspect of construction workers' safety behaviors, several key limitations exist throughout much of literature. First, while previous studies have provided empirical evidence on the existence of social influence on workers' safety behaviors, very little attention has been given to the fundamental characteristics of construction workforces, which make safety norms uniquely complex in construction. In a traditional long-term organization, all organization members and different levels of management (e.g., top and front-line management) share a company identity as their common background, which forms a favorable environment for coherent social norms in the organization (Litwin and Stringer Jr 1968; Tyagi 1982). However, in the case of construction, most members and managers have different organizational backgrounds. For example, a project manager from a general contractor and supervisors of subcontractors belong to different companies. Workers, meanwhile, have a strong identification with their trades (or unions) and workgroups (i.e., crews). As a result, multiple organizational backgrounds and social norms coexist in construction projects, which makes it very challenging to develop and maintain coherent safety norms in a construction project. Furthermore, since crew members brought by a general contractor and subcontractors are hired temporarily for a specific project, their tenure at a construction site is relatively short. The limited time employees' interactions with management more task-oriented than relationship-oriented and this can hinder the development of coherent norms in a temporary organization (Bryman et al. 1987; Clarke 2003). However, these fundamental characteristics of construction workforce organizations affect social influence process on workers' safety behaviors are not well understood (Bartels et al. 2007; Peters et al. 2013)

Additionally, despite the increasing attention paid to the socio-cognitive aspect of workers' safety behaviors, there is a notable paucity of studies investigating the mechanism behind the relationship between cognitive process, social influence, and safety behavior. While previous studies have suggested theoretical models of the cognitive process of safety behavior and provided empirical evidence on the social influence on safety behavior, little is known about how the cognitive process interacts with social influence process. Also, while a few studies have incorporated social aspects in the cognitive model of safety behavior, they have not yet paid sufficient attention to how the socio-cognitive process interacts with different environmental conditions (e.g., different site risk and safety management practices). Although the cognitive model explains the cognitive steps involved when a worker interacts with the environment (i.e., site risk), it is limited to investigating how different site risk conditions interact with the socio-cognitive process to affect safety behaviors. Furthermore, empirical evidence on the relationship between management actions and safety behavior from the previous studies is not enough to explain how different safety management strategies induce workers' behavioral changes in the construction projects.

Further, relatively little is currently known as to how workers' safety decision-making processes respond to actual risk during their work. In the safety decision-making process, risk perception is very important because it is the step that directly interacts with the risk during making safety decisions. Traditionally, risk perception has been understood as the result of the analysis. In these approaches, perceived risk is determined by individual's assessment of the likelihood and severity of the accident (Reference). Surveys and interviews have been conducted to measure construction workers' perceived risk during their work (Hallowell 2010; Tixier 2014). However, current approaches to measure workers' perceived risk are post hoc and thus incapable of showing dynamic changes during ongoing work. Also, it may not be free from the self-reported bias which is inherent in the subjective scale (Morris 1995; Wang and Cheong 2006). Finally, asking workers to respond to the questionnaire could be cumbersome and interrupt their ongoing tasks. As a result, there is an increased need for objective and nonintrusive methods that can continuously measure workers' perceived risk.

1.4 RESEARCH OBJECTIVES AND APPROACHES

With this background, the overarching goal of this research is threefold: 1) to improve our understanding of the role of different safety norms and social identities in workers' safety behaviors; 2) to enhance our understanding of how workers' safety decision-making processes and their interaction with the environments (i.e., coworkers, managers, risk conditions, safety management practices) affect workers' safety behaviors; and 3) to explore advanced methods to deepen our understanding of interaction between safety decision-making process and risk during the work.

1. **To identify the current status of safety norms and social identities at construction sites**: Multiple organizational backgrounds in construction projects and workers' short tenure make it very challenging to develop and maintain coherent safety norms in construction projects. However, little is known about the misalignment between different safety norms in construction projects workers' social identification with different groups in their projects. Before exploring the social influence on workers' safety behavior, the current status of safety norms and social identities should be understood first.

2. **To explore the effect of different safety norms and social identities on workers' safety behaviors**: It is not clear at this time how different safety norms and social identities contribute to workers' safety behaviors in construction. Since previous studies have focused on proving the existence of social influence, we have a limited understanding of under what condition and through which processes social norms influence workers' safety behaviors. To enhance our understanding of social influence, the relationship between workers' perceptions of different safety norms, social identities, and their safety behaviors needs to be identified.

3. **To identify the impact of different cultural backgrounds and organizational structure on social influence process:** Since culture is involved with individuals' shared beliefs and values regarding how things ought to be or how one should behave, cultural background can shape an individual's response to social influence. More, the construction industry's unique organizational structure (i.e., subcontract) makes social influence more complicated in a construction project. However, there is a notable paucity of studies investigating the

effects of different cultural backgrounds and organizational structures on social influence processes.

4. **To create a formal behavioral model for safety behaviors in order to explore the mechanism behind the link between social influence, decision-making process, and safety behaviors**: A formal model to represent the socio-cognitive processes of workers' safety behavior will help improve our understanding of the mechanisms behind the relationship between cognitive process, social influence, and safety behaviors. Once validated, the model can be used to conduct hypothetical experiments and test the effectiveness of different safety management strategies to reduce workers' unsafe behaviors in different site risk conditions.

5. **To examine the potential of advanced technologies (i.e., wearable devices) for continuously monitoring of workers' perceived risk:** Methodological hurdles to measuring workers' response to risk had remained the primary obstacle for continuous monitoring of workers' perceived risk. Recent advancements in psychophysiology and wearable technologies make it possible to overcome the methodological limitations. Since an aroused autonomic nervous system by an external stimulus results in changes in physiological responses within our bodies, physiological responses could be an important source to understand workers' perceived risk. However, the potential of using physiological responses collected from wearable devices to understand perceived risk has not been investigated.

To achieve these research objectives, I have developed a research framework that applies an interdisciplinary research approach as shown in Figure 1.1. When a worker confronts a potential hazard, he/she observes the environment (e.g., site condition, coworkers, and managers) to acquire the information needed to make a decision. Based on the information, the worker performs the cognitive process, and it results in a behavioral response (i.e., safe or unsafe action). In addition, there will be physiological responses during the decision-making process. For example, if the worker perceives a significant risk, his/her nervous system reacts, and distinguishable changes in physiological responses will occur.

To incorporate all the processes, the current status of safety norms and social identities are identified using behavioral economic experiments and surveys and statistical analyses (Research Objective #1). Based on the findings from the first study, a theoretical model of the social influence of construction workers' safety behaviors has been developed and empirically tested (Research Objective #2). Group analyses have been conducted to examine the different patterns of social influence in different cultural backgrounds and organizational structures (Research Objective #3). A computer simulation modeling that integrates workers' safety decision-making processes and social influence has been developed to explore the effects of the socio-cognitive mechanism of safety behaviors (Research Objective #4). Finally, field study has been conducted to examine the potential of using workers' physiological sensory data collected from wearable devices to understand their perceived risk during ongoing work (Research Objective #5).

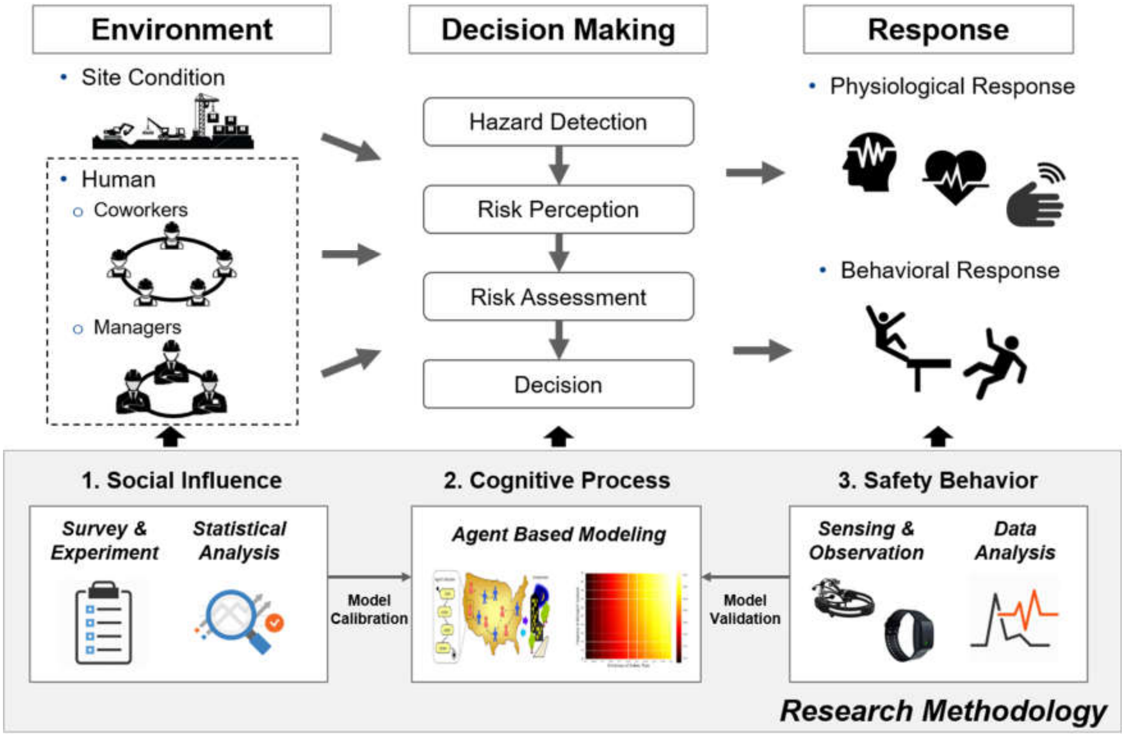


Figure 1.1 Research Framework

1.5 THE STRUCTURE OF THE DISSERTATION

This dissertation is a compilation of the studies used to achieve the proposed research objectives. This dissertation is composed of seven chapters. Chapter 1 and Chapter 7 provide the introduction and conclusion of this work. Chapters 2 through Chapter 6 introduce each of the studies that corresponds to an aforementioned research objective. The following is the list of the chapters.

Chapter 1: Introduction. This chapter introduces the background, problem statements, and objectives and approaches of the entire research effort.

Chapter 2: Current Status of Safety Norms and Social Identities at Construction Sites. This chapter presents the results of behavioral economic experiments that measure and compare safety norms shared by workers as opposed to safety norms by managers to identify the current status of safety norms in construction projects. Additionally, this chapter also presents an explanatory analysis of workers' social identification with different groups in their job site (i.e., workgroup, company, project, union, and trade)

Chapter 3: The Role of Safety Norms and Social Identifications in Construction Workers' Safety Behaviors. This chapter develops and empirically tests a theoretical model that explains the relationship between different safety norms, social identities, and safety behaviors. Additionally, relationships among the variables are analyzed using statistical analyses.

Chapter 4: The Effects of Cultural Backgrounds and Organizational Structures on Social Influence Process. This chapter compared the patterns of social influence and workers' social identification in different cultural backgrounds (i.e., individualistic culture and collective culture) and different organizational structure (i.e., subcontracting system and direct hiring of workers) using group analyses.

Chapter 5: An Empirically Based Agent-Based Model of the Socio-Cognitive Process of Construction Workers' Safety Behavior. This chapter presents a study that details the creation and development of a behavioral model for workers' safety behavior grounded in empirical findings from previous chapters. This model then used to test different safety management strategies in different site risk conditions.

Chapter 6: Potential of Physiological Sensory Data to Understand Construction Workers' Perceived Risk. This chapter investigates the effect of high-risk activities on workers' physiological responses during their ongoing work. This chapter also presents the results of field studies that examine the feasibility of wearable devices to understand workers' perceived risk during at construction sites.

Chapter 7: Conclusions and Recommendations. This chapter provides a summary of the conclusions that can be drawn from the research. Several recommendations for future work stemming from this research are also provided.

CHAPTER 2

CURRENT STATUS OF SAFETY NORMS AND SOCIAL IDENTITIES AT CONSTRUCTION SITES[2]

2.1 INTRODUCTION

An accident occurs when workers' unsafe behavior coincides with unsafe work conditions (Heinrich et al., 1950; Lingard and Rowlinson, 2005; Choudhry and Fang, 2008). Traditionally, the efforts to improve construction safety have been focused on improving the physical work environment and work procedures on construction sites (Fogarty and Shaw, 2010; Chen and Jin, 2013), and as a result of these efforts, there have been considerable improvements in work environment and procedures in construction over the past several decades (Shin et al., 2014). However, given that 80 – 90% of accidents are associated with workers' unsafe behaviors (Heinrich et al., 1980; Suraji et al., 2001; Choudhry and Fang, 2008), attention to the improvement of workers' behavior for safety is on the rise, resulting in the development of programs designed to improve workers' safety attitudes and behavior—i.e., behavior-based safety (Seo, 2005; Chen and Jin, 2013; Fang et al. 2015).

A large number of factors, including predisposition, experience, education, training, cultural backgrounds, contractual conditions, and organizational settings, can affect workers' safety behavior (Sawacha et al. 1999). Among such factors, the social aspect of workers' safety behavior

[2] This chapter is adopted from Choi, B., Ahn, S., and Lee, S. (2017) "Construction Workers' Group Norms and Personal Standards Regarding Safety Behavior: Social Identity Theory Perspective." *Journal of Management in Engineering*, 33(4), 04017001

has recently commanded increased attention as more evidence demonstrates that workers' safety behavior is under the great influence of collective perception and social norms related to safety policies and required safety behavior—often referred to as safety climate and safety norm. Such research efforts focusing on workers' safety behavior have shown that workers' shared perceptions and consensus about safety play an important role in shaping their safety attitudes and behavior in organizations (Glendon and Litherland, 2001; Jiang et al., 2014; Choi and Lee 2016). A number of empirical studies have demonstrated that workers' safety behavior is influenced by their perception of organizational safety policies, procedures, and practices—often referred to as safety climate (Zohar, 1980; Neal et al., 2000; Mohamed, 2002; Clarke and Ward, 2006; Zhang et al. 2016)—and by their perception of others' behavior—often referred to as safety norms (Brondino et al., 2012; Zhang and Fang, 2013; Goh and Binte Sa'adon, 2014; Choi et al. 2015). Therefore, it is important to make sure that workers have favorable perceptions and consensus about safety behavior for achieving safety in construction projects.

However, the complex nature of the construction workforce makes it very challenging to develop and maintain favorable perception and consensus about safety behaviors in construction projects. Construction workers hold multiple identities while working on a project. Examples of the groups with which construction workers might identify themselves while working on a project are union, trade, workgroup, company, and project. Sharing the same identity plays an important role in forming and maintaining coherent safety norms among the project participants. According to the social identity theory, an individual's identification with the group is an important mechanism that moderates the effects of group norms on an individual's behavior (White et al. 2009). In other words, people who strongly identify with a group are more likely to internalize and adhere to the group norms (Wood 2000; Smith et al. 2007; Smith and Louis 2008). On the other hand, the group norms may not be influential to people who do not identity with the group. Therefore, construction workers' social norms might be distant from management norms regarding safety behavior if workers do not identify themselves with the project. However, it is currently unclear regarding misalignments among safety norms and the currents status of workers' social identification in construction projects.

2.2 RESEARCH OBJECTIVE AND HYPOTHESES

Despite the importance of group norms and social identities in individuals' behaviors in organizations, little is known about to the current status of safety norms and social identities, what extent construction workers' safety attitudes and behavior are influenced by group norms, and to what extent social identification is involved in this process. To reduce the knowledge gap, this study aims to identify: (1) the current status of safety norms and social identities, (2) the influence of group norms on construction worker's personal standards regarding safety behavior and (3) the impact of social identification on the influence that group norms have on construction workers' personal standards regarding safety behavior.

Specifically, the following five hypotheses are tested with empirical data in this study:

- Hypothesis 1: *Perceived group norms, which refer to the perception of coworkers' attitudes and behavior are significantly different from the norms desired by project managers regarding safety behavior.*
- Hypothesis 2: *Perceived group norms are significantly correlated with construction workers' personal standards regarding safety behavior.*
- Hypothesis 3: *The salience of social identity is significantly different between the multiple social identities that construction workers have at work.*
- Hypothesis 4: *Construction workers' salience of social identity with a workgroup is significantly correlated with the alignment between their perceived workgroup norms and personal standards regarding safety behavior.*
- Hypothesis 5a and 5b: *Construction workers' time spent in a workgroup or a project is significantly and positively correlated with the salience of social identity with the workgroup (5a) or the project (5b).*

These hypotheses are conjectured based on the characteristics of the construction workforce and the social identity theory. Hypothesis 1 tests whether or not safety norms shared by construction workers are aligned with the norms desired by project managers. Considering the multiple organizational backgrounds in a construction project due to its unique organizational structure (i.e., temporary organizations based on subcontracting), one can hypothesize that safety norms shared by construction workers not be aligned with project managers' desired norms if workers' unsafe actions have been observed. In other words, a test of Hypothesis 1 is thought to shed some light on the current status of safety norms at construction sites.

Hypothesis 2 tests whether or not group norms influence individual construction workers' personal standards regarding safety behavior. Many researchers have provided theoretical and/or empirical evidence that an individual's behavior is influenced by the behavior and social norms of others in his/her group (Festinger 1954; Bandura 1991; Deutsch and Gerard 1955; Asch 1956; Cialdini et al. 1991; White et al. 2009). In addition, a number of studies have specifically presented empirical evidence of social influence on safety behavior (Cooper 2000; Neal et al. 2000; Mohamed 2002; Clarke and Ward 2006; Choudhry et al. 2007). If empirical data support Hypothesis 2, therefore, it can be proven that construction workers' safety behavior is under the influence of group norms. Hypothesis 3 tests whether or not there is a difference in the salience of social identity within the different groups construction workers belong to. This hypothesis addresses the unique nature of employment and membership of construction workers. As mentioned previously, due to the multiple and temporary nature of membership, construction workers' social identities with the different groups they belong to may have different levels of significance to them. Hypothesis 3 tests this idea.

Hypothesis 4 tests whether or not construction workers' acceptance of the safety-behavior-related norms of a group is affected by their level of social identification with the group. The social identity theory states that group norms are internalized through social identification with the group and this is the process by which individuals' behavior is put under the influence of social norms (Ashforth and Mael 1989; Terry and Hogg 1996; Hogg and Terry 2000). Hypothesis 4 tests this idea within the context of construction workers' safety behavior. If empirical data support this hypothesis, it can be proven that construction workers' identification with a group drives their acceptance of the norms of the group regarding safety behavior.

Last, Hypothesis 5 tests whether there is any significant impact of the time spent with a temporary group—e.g., a project or a workgroup—on the salience of social identity with the group. According to the social identity theory, the degree by which an individual observes other group members and its consequences are an important factor of his/her social identification with the group because frequent interactions with group members can increase the cognitive accessibility of the group identity (Oakes et al., 1991; Turner et al., 1994). Therefore, one can assume that construction workers who have spent a long time within a project or a workgroup would have a strong feeling of membership and identify themselves with the group. Hypothesis 5 tests this idea.

2.3 METHOD

2.3.1 Measurement of safety norms shared by workers and shared by managers

To measure safety norms in construction projects, a behavioral economic experiment following the norm elicitation protocol developed by Burks and Krupka (2012) was used in this study. The norm elicitation protocol has been used to quantify group norms in various contexts such as ethical dilemmas in a financial service organization (Burks and Krupka 2012), a three-person gift change (Gächter et al. 2013) and a dictator game (Erkut et al. 2015). In this protocol, participants are given a situation where several different actions can be taken in a given circumstance and asked to rate the appropriateness of each of the different actions in an incentivized coordination game structure (Ahn et al. 2015).

Among the situations concerning safety behavior, the working at a height situation was used in this study. Because fall protection is one of the most frequently cited violations and main causes of fatalities in the construction industry in U.S., using "the height situation" is particularly appropriate (OSHA 2014; Jebelli et al. 2015). During the experiment, participants read a statement that describes a hypothetical situation as follows: "Please imagine that Robert is a member of your workgroup, and he works at a workspace where a fall protection is required by the OSHA regulation." After reading it, participants were asked to evaluate the appropriateness of different actions that Robert might choose in the given situation. Five action scenarios related to connecting "snap hooks"—a common tying system for fall protection equipment—were developed for this experiment, as follows:

- Action 1. *Robert does not connect his snap hooks to an anchor point even if he works on a dangerous task and the fall protection system does not bother his work.*

- Action 2. *Robert connects his snap hooks to an anchor point only when he perceives a danger of falling and the fall protection system does not bother his work.*
- Action 3. *Robert connects his snap hooks to an anchor point only when he perceives a danger of falling.*
- Action 4. *Robert always connects his snap hooks to an anchor point whenever a fall protection is required. However, he continues to work even if he cannot find an object onto which he can securely connect his snap hooks.*
- Action 5. *Robert always connects his snap hooks to an anchor point. If he cannot find an object he can securely connect his snap hooks to, he does not continue to work.*

Here, these five actions are presented in order of appropriateness as conjectured prior to the experiment (Action 1 is least appropriate, and Action 5 is most appropriate). However, they were presented in a random order in the experiment to minimize the response order effect.

Then, participants of this experiment were asked to rate the appropriateness of each of these five actions on a 4-point Likert scale ('very inappropriate,' 'somewhat inappropriate,' 'somewhat appropriate,' and 'very appropriate'). The norm elicitation protocol adopts a 4-point Likert scale to prevent a focal point from emerging by just having a central/neutral term in the options (Burks and Krupka 2012). To capture construction workers' perception of group norms and personal standards separately, worker participants were asked to complete the rating task twice. On the first pass, worker participants were asked to try to match their appropriateness rating with those of a typical member of their group. They were told that their responses would be compared with the responses of a randomly selected member of their group, and that they would be rewarded for every matched response—i.e., a coordination game structure. Participants were informed that 10 % of all the participants will be randomly selected at the end of this experiment, and the selected individual will receive $10 for each matched response. For example, a participant received $50 if he/she was selected and his/her responses for all five actions were identical with those of another randomly selected participant. With the expectation of the incentives, participants are encouraged to think about how others would evaluate those actions, and this is how shared group norms can be elicited through the experiment. The responses collected from the worker participants' first pass can be interpreted as the perception of attitudes of his/her group members, i.e., perceived group norms.

On the second pass, worker participants were asked to provide their own personal ratings without trying to match anyone else's ratings. Therefore, the responses collected from the worker participants' second passes can be interpreted as workers' personal standards. In order to prevent the effect of consistency motif (Podsakoff et al. 2003) between the two passes, five actions were presented in a different order in the two passes. Based on the randomly determined order of the actions in the first pass, the order of the actions in the second pass was manipulated so that the order is not the same from the first pass. In addition, in order to ensure that responses in the second pass are made separately from the first pass, respondents were given the tasks of the second pass after a short break (approximately five minutes). During the break, the experiment administrators provided participants with instructions for how to respond to the items in the second pass. In determining what is elicited in the first and second pass, the authors considered how personal standards or workgroup norms are intuited. Personal standards mean that a set of behaviors are intuitively acceptable or legitimate to the person. On the other hand, group norms are usually perceived unconsciously, and thereby more difficult to recall or describe. Therefore, to prevent the response to the items regarding personal standards from overriding or contaminating the response to the items regarding group norms, in the norm elicitation protocol the group norms are elicited first using the coordination game setting and then the personal standards are elicited (e.g., Burks and Krupka 2012; Gächter et al. 2013; Erkut et al. 2015).

Likewise, project manager participants were also asked to conduct the rating task twice. On the first pass, project manager participants were asked to try to match their appropriateness rating with those of a typical worker at their site, and they were told that their responses would be compared with the responses of a randomly selected worker and be rewarded for every matched response. Therefore, the responses collected from the project manager participants' first pass can be seen as project managers' beliefs about social norms shared by the workers in their project, i.e., project managers' perception of worker's safety norms. On the second pass, they were asked to try to match their appropriateness ratings with the fellow managers at their site, and they were told that their responses would be compared with the responses of a randomly selected manager and be rewarded for every matched response. Therefore, the responses collected from the project manager participants' second passes can be interpreted as the norms desired by project managers. Table 2.1 summarizes the norms and personal standards that are elicited from each pass in the experiment.

Table 2.1 Norm Elicitation Protocol Structure

Participants	**Target to match with**	
Workers	**Other workgroup members**	**No others**
	Workers' perceived group norms	Worker's personal standards
Managers	**Workers**	**Other managers**
	Manager's belief about worker's safety norms	Manager's desired norms

2.3.2 Measurement of the salience of social identities

Previous research efforts to measure the salience of social identity used three interrelated dimensions of social identity—i.e., cognitive dimension, affective dimension, and evaluative dimension (Ellemers et al., 1999; Bergami and Bagozzi, 2000; Bagozzi and Lee, 2002; Jackson, 2002). The cognitive dimension of social identity refers to the awareness of one's membership in a group (Tajfel, 1978). To measure the cognitive dimension, two survey items were adapted from Mael and Ashforth (1992)'s questionnaire items and used in this research: "When I talk about my workgroup, I usually say we rather than they," and "When someone criticizes my workgroup, it feels like I am criticized." The affective dimension of social identity refers to the sense of emotional involvement with the group (Ellemers et al., 1999; Bergami and Bagozzi, 2000). To measure the affective dimension, two survey items were adapted from Bergami and Bagozzi (2000)'s questionnaire items and used in this research: "I am happy to be a member of my workgroup" and "I am attached to my workgroup". The evaluative dimension of social identity refers to a positive or negative value or connotation attached to the group membership (Ellemers et al., 1999; Bagozzi and Lee, 2002). To measure evaluative dimension, two items were adapted from Ellemers et al. (1999)'s questionnaire items and used in this research: "I am proud to be a member of my workgroup" and "I have respect for my workgroup". Every item was measured on a 7-point Likert scale was used: -3 = 'strongly disagree', -2 = 'disagree', -1 = 'somewhat disagree', 0 = 'neither disagree nor agree', 1 = 'somewhat agree', 2 = 'agree', 3 = 'strongly agree'. This kind of 7-point Likert scale items have been widely used in social identity measurement (e.g., Ellmers et al. 1999; Schubert and Otten 2002; Jackson 2010).

As mentioned previously, construction workers may have multiple social identities while working on a job site, and the level of social identification for each identity may vary. Five groups with which a typical construction worker may identify him/herself were identified prior to the surveys: union, trade, workgroup, company, and project. Every item for measuring the dimensions of social identity was repeated for all of the five groups (i.e., identities) in the survey questionnaire. Hence, the survey questionnaire contained a total of 30 items (2 items per each social identity dimension × 3 dimensions × 5 identities) for measuring all the dimensions of social identity for all the groups.

2.3.3 Participants and Procedure

For data collection, three different building construction sites were approached. Site A was a new research facility building construction project. The data were collected from this site during May 2014. Site B was a large sized library building retrofit project. The data were collected from this site during September 2014. Site C was a large sized research facility retrofit project. The data were collected from this site during December 2014. A total of 106 workers (26 workers from site A, 45 workers from site B, and 35 workers from site C) and 9 project managers (3 project managers from each site) participated in the study. All of these three construction sites were located in Ann Arbor, Michigan, US. All worker participants were male union workers, and the workers had been involved in their current project for 4.6 months on average. All project manager participants were male, had 10+ years of experiences in construction management, and had been involved in their current project from the project's onset.

Before the data collection, the data collection instruments and experiment/survey procedures were reviewed and approved by Institutional Review Board (IRB) of the University of Michigan. The behavioral experiment along with the survey was taken in sequence on the same day. Workers participated in both the behavioral experiment (i.e., norm elicitation) and the survey (i.e., social identity measurement), whereas project managers participated only in the experiment. The experiment and surveys took place during break times to avoid interruptions on the construction tasks. One week prior to the experiment, the administrators advertised the purpose and process of the study to the foremen in a weekly meeting, and the foremen advertised the study to their workgroup members. Then, the workers at the sites voluntarily participated in the behavioral experiment and surveys using their break times. Before starting the experiment, the administrators provided a brief explanation of the purpose and processes of the study including the information about the incentives. The experiment and the survey took approximately 25–30 minutes in total to complete. Every participant was paid a $10 participation fee.

After the data collection, 14 responses from a total of 106 responses from workers were removed from the sample due to incompleteness. Additionally, 10 responses from a one-person-group—only one group member from a particular group participated in the experiment—were also removed from the sample because of the impossibility of defining the group norms of their group based on a single response. After removing these incompatible responses, a total of 82 responses from workers (of 12 different trades, of 13 different companies, and of 19 different groups) and 9 responses from project managers were used in the data analysis.

2.4 RESULTS

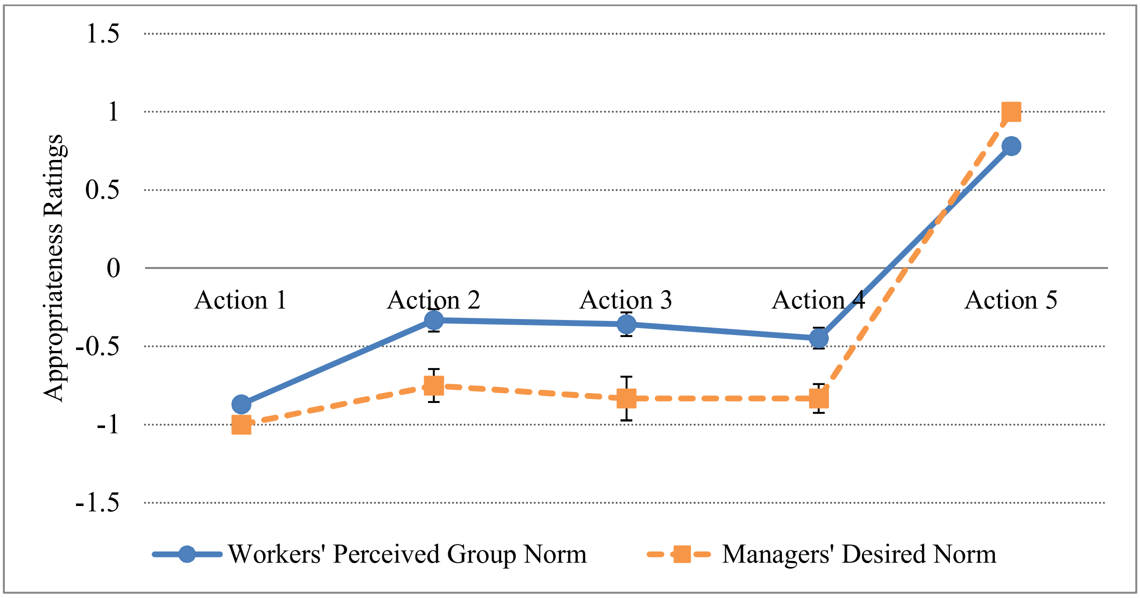
2.4.1 Misalignment between workers' perceived group norms and the norms desired by project managers

Participants' appropriateness ratings of the actions collected from the behavioral experiment were converted into numerical scores for quantitative analysis: -1 = 'very inappropriate', -1/3 = 'somewhat inappropriate', 1/3 = 'somewhat appropriate', and 1 = 'very appropriate'. The mean and the standard deviation of the appropriateness ratings from each pass for each action are presented in Table 2.2.

Table 2.2 Mean and Standard Deviation for Participants' Appropriateness Rating

	Worker's perceived group norms (N=82)		**Worker's personal standards (N=82)**		**Manger's belief about worker's safety norms (N=9)**		**Manager's desired norms (N=9)**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Action 1	-0.87	0.38	-0.89	0.32	-0.78	0.33	-1.00	0.00
Action 2	-0.33	0.69	-0.37	0.66	-0.11	0.75	-0.78	0.33
Action 3	-0.36	0.65	-0.36	0.69	-0.11	0.69	-0.85	0.44
Action 4	-0.45	0.64	-0.46	0.61	-0.19	0.73	-0.85	0.29
Action 5	0.78	0.41	0.76	0.44	0.48	0.65	1.00	0.00

The average of workers' perceived group norms and the average of the norms desired by project managers are shown in Figure 2.1. Figure 2.1 shows that there were measurable differences between workers' perceived group norms and the norms desired by project managers regarding safety behavior; project managers agreed that Actions 1 – 4 are very inappropriate and only Action 5 is very appropriate, while workers agreed that Action 1 is very inappropriate, but Actions 2 – 4 are only somewhat inappropriate. This shows that group norms shared by workers regarding safety behavior were more lenient in general than the norms desired by project managers. Figure 2.1 also shows that the misalignment was relatively large for Actions 2, 3, and 4, while the misalignment was very small for Action 1 and 5. This shows that the misalignment between construction workers' perceived group norms and the norms desired by project managers is small for obviously appropriate or inappropriate actions, and the misalignment is relatively large for the actions with subtleties.



Note: Mean evaluations with stanard errors

Figure 2.1 Workers' Perceived Group Norms and Managers' Desired Norms

To statistically test the difference between workers' perceived group norms and the norms desired by project managers (i.e., Hypothesis 1), independent sample t-tests were conducted for each action. As shown in Table 2.3, the result of the tests shows that that the misalignment between workers' perceived group norms and the norms desired by project managers was significant for every action. Specifically, negative mean differences were found for the inappropriate actions (-0.13 for Action 1, -0.45 for Action 2, -0.49 for Action 3, and -0.40 for Action 4), and a positive mean difference was found for the appropriate action (0.22 for Action 5). This means that project manager's desired norms were statistically significantly stricter than workers' perceived group norms regarding safety behaviors. For example, for Action 3 ("Robert connects his snap hooks to an anchor point only when he perceives a danger of falling"), workers' perceived group norms (-0.36) were close to 'somewhat inappropriate', whereas the norm desired by project managers (-0.85) was close to 'very inappropriate.' With these results, Hypothesis 1 was accepted.

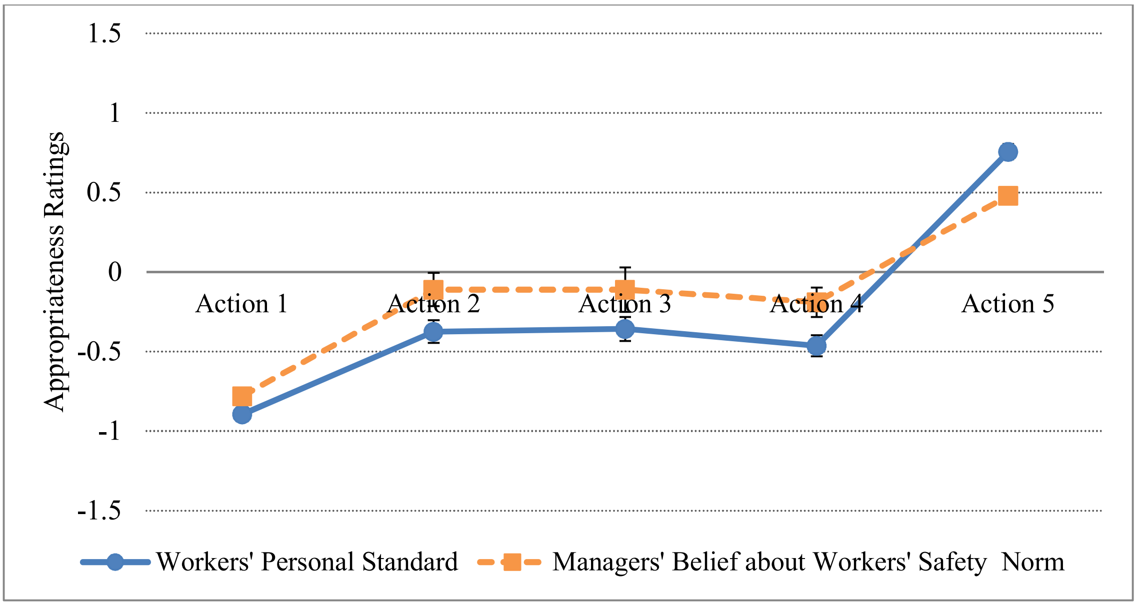
Table 2.3 Results of Independent t-tests between Managers' Desired Norms and Workers' Perceived Group Norms

Actions	Manager's desired norm			Workers' perceived group norms			95% CI for Mean Difference	t	df
	Mean	SD	N	Mean	SD	n			
Action 1	-1.00	0.00	9	-0.87	0.38	82	-0.21, -0.05	-3.07**	81.00
Action 2	-0.78	0.33	9	-0.33	0.69	82	-0.73. -0.16	-3.29**	17.07
Action 3	-0.85	0.44	9	-0.36	0.65	82	-0.85, -0.14	-3.00**	12.13
Action 4	-0.85	0.29	9	-0.45	0.64	82	-0.66, -0.15	-3.36**	17.85
Action 5	1.00	0.00	9	0.78	0.41	82	0.13, 0.31	4.89**	81.00

Note: Welch-Satterthwaite approximation employed due to unequal group variances.

* $p < .05$, ** $p < .01$

In addition, the average of workers' personal standards and the average of the project managers' belief about workers' safety norms are shown in Figure 2.2. Figure 2.2 shows that there is also some difference between workers' personal standards and project managers' belief about the workers' group norms for Action 2 – 5; workers evaluated that Action 2 – 4 are somewhat inappropriate, while Action 5 is very appropriate. On the other hand, project managers believed that their workers will evaluate that Action 2 – 4 is neither appropriate nor inappropriate, while Action 5 is only somewhat appropriate. This shows that project managers tended to believe that workers' personal standards regarding safety behavior are even more lenient than they actually are. However, independent t-tests showed that the difference between project managers' beliefs about workers' group norms and workers' actual group norms was not statistically significant for every Action.



Note: Mean evaluations with standard errors

Figure 2.2 Workers' Personal Standards and Managers' Belief about Workers' Safety Norms

2.4.2 Influence of group norms on personal standards

Next, whether or not workers' personal standards are significantly correlated with their perceived group norms (i.e., Hypothesis 2) was tested by using Ordinary Least Squares (OLS) regressions. Table 4 shows the results of the OLS regressions. As shown in Table 2.4, workers' personal standards were significantly correlated with the perceived group norm for Action 2 (β = 0.70, $t(55) = 6.97$, $p < 0.01$), Action 3 (β = 0.66, $t(55) = 6.84$, $p < 0.01$), Action 4 (β = 0.34, $t(55)$ = 2.94, $p < 0.01$), and Action 5 (β = 0.61, $t(55) = 5.66$, $p < 0.01$). The regression coefficient was not significant for Action 1 (β = -0.13, $t(55) = -1.00$, $p > 0.32$). Therefore, Hypothesis 2 was marginally accepted.

Table 2.4 Results of OLS Regression for the Relationship between Workers' Personal Standards and Perceived Group Norms

Predictor	Regression Results	Dependent variable: personal standard				
		Action 1	Action 2	Action 3	Action 4	Action 5
Perceived group norm	B	-0.11	0.66**	0.70**	0.33**	0.66**
	SE B	0.11	0.09	0.10	0.11	0.11
	β	-0.13	0.70**	0.66**	0.34**	0.61**
	Observation	82	82	82	82	82
	R^2	0.29	0.64	0.64	0.51	0.55

Note: ** $p < .01$

2.4.3 Salience of social identities in construction workers

Table 2.5 shows the mean, standard deviation, and reliability score of the social identity measures for different groups. In general, the reliability scores from the different items used to measure the dimensions of social identity exceeded the acceptable level of 0.6 (Hair et al. 2006; Patel and Jha 2016), which reaffirmed that the three dimensions of social identity are reliable.

Table 2.5 Means, Standard Deviations, and Reliability Scores for Social Identity Measures

Group	Dimension	Level of Social Identification (N = 82)		
		Mean	SD	Reliability
Workgroup	Overall	1.92	0.68	0.70
	Cognitive	1.65	1.17	0.72
	Affective	1.87	0.85	0.62
	Evaluative	2.23	0.71	0.84
Company	Overall	1.47	1.11	0.88
	Cognitive	0.98	1.69	0.90
	Affective	1.48	1.18	0.76
	Evaluative	1.96	0.96	0.89
Project	Overall	1.20	1.06	0.85
	Cognitive	0.29	1.48	0.67
	Affective	1.32	1.14	0.66
	Evaluative	2.00	1.07	0.92
Trade	Overall	2.27	0.82	0.88
	Cognitive	1.95	1.26	0.78
	Affective	2.32	0.87	0.86
	Evaluative	2.54	0.63	0.93
Union	Overall	1.89	1.25	0.93
	Cognitive	1.62	1.57	0.88
	Affective	1.93	1.32	0.91
	Evaluative	2.13	1.23	0.89

Figure 2.3 shows a graphical representation of the descriptive analysis. In Figure 2.3, each vertex of a triangle is the mean score of the sample for each dimension of social identity, and each of five triangles represents an identity (i.e., union, trade, workgroup, company, and project). The larger the size of the triangle, the more salient the identity is. Therefore, Figure 2.3 shows that workers in general had the highest level of social identity with their trade, and the lowest level of social identity with the project. It is worth noting that the cognitive dimension of workers' project identity was minimal when compared to the cognitive dimensions of other identities.

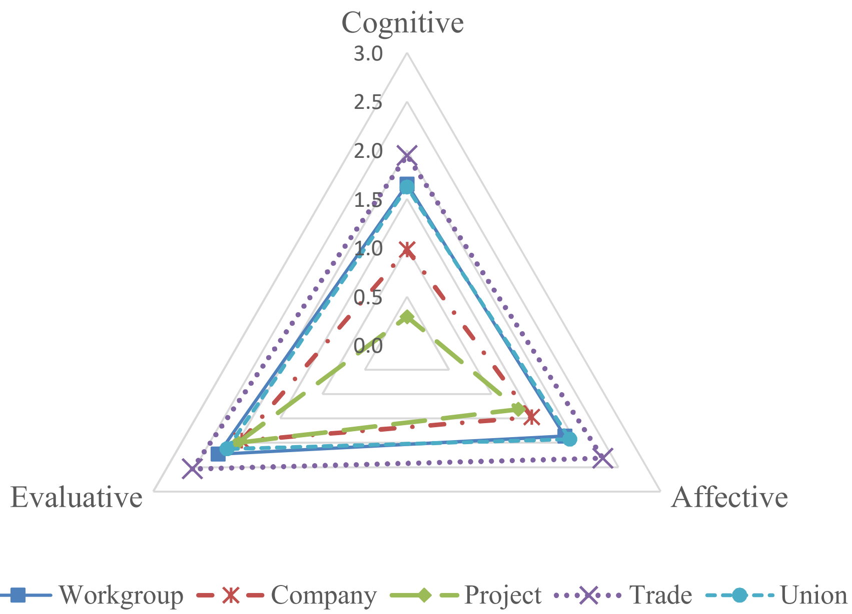


Figure 2.3 Current Staus of Worekrs' Social Identifications

To demonstrate the statistical significance of this pattern, whether or not the salience of social identity is different between the social identities (i.e., Hypothesis 3) was tested using paired t-tests for all possible pairs of social identities. To prevent false positive errors associated with multiple comparisons, results of the paired t-test were corrected by Bonferroni correction. Table 2.6 shows the result of the paired t-tests.

Table 2.6 Results of Paired t-tests between Social Identities

Pair	Mean Difference	SD	t	df
Workgroup – Company	0.445	0.998	4.040**	81
Workgroup – Project	0.713	0.964	6.701**	81
Workgroup – Trade	-0.350	0.807	-3.923**	81
Workgroup – Union	0.024	1.276	0.173	81
Company – Project	0.268	1.041	2.334	81
Company – Trade	-0.795	1.221	-5.894**	81
Company – Union	-0.421	1.512	-2.519	81
Project – Trade	-1.063	1.041	-9.245**	81
Project – Union	-0.689	1.446	-4.315**	81
Trade – Union	0.374	1.018	3.328*	81

Note: p-values were corrected by Bonferroni correction, * $p < .05$, ** $p < .01$

As shown in Table 2.5 and 2.6, the trade identity (M = 2.27, SD = 0.82) was most salient in construction workers, and the mean difference between the trade identity and all other identities was statistically significant. The workgroup identity (M = 1.92, SD = 0.68) was the second in the level of salience. The difference of the salience between the workgroup identity and other identities were statistically significant except for the union identity. The union identity (M = 1.89, SD = 1.25) and the company identity (M = 1.47, SD = 1.11) followed the workgroup identity in the level of salience. The mean difference between them was not significant. The project identity (M = 1.20, SD = 1.06) was least salient, and the difference between the project identity and all other identities was statistically significant except for the company identity.

2.4.4 Impact of the salience of social identities on the influence of group norms on personal standards

To investigate the impact of the salience of social identity on the influence that group norms have on personal standards regarding safety behavior, a misalignment measure was defined to quantify how distant an individual's personal standards are from his/her perceived group norms. The measure takes the absolute value of the difference between an individual's perceived group norm and his/her personal standard for each of the actions, and sums these over all the actions:

$$M_i^{PS,PN} = \sum_{j=1}^{5} \left| Evaluation_{ij}^{PN} - Evaluation_{ij}^{PS} \right|$$

where $Evaluation_{ij}^{PN}$ is worker *i*'s perceived group norm for action *j*, and $Evaluation_{ij}^{PS}$ is worker *i*'s personal standard for action *j*.

Then, a correlation analysis was conducted to see whether the misalignment measure and the measures of the dimensions of the workgroup identity are significantly correlated (i.e., Hypothesis 4). The result of the correlation analysis revealed that the misalignment measure had a significant negative correlation with the affective dimension of the workgroup identity ($r = -0.29$, $p < 0.01$) and the evaluative dimension of the workgroup identity ($r = -0.24$, $p < 0.05$). However, the correlation between the misalignment measure and the cognitive dimension of the workgroup identity was not significant ($r = -0.09$, p = n.s). A direct interpretation of these results finds that the affective dimension and the evaluative dimension of the workgroup identity moderate the influence that group norms have on personal standards regarding safety behavior in construction workers. In other words, the results show that a worker who has a high level of attachment toward his/her workgroup and a high level of respect for his/her workgroup tends to have personal standards aligned with perceived group norms regarding safety behavior. With these results, Hypothesis 4 is also marginally accepted.

2.4.5 Relationship between time spent in a group and salience of social identity

Next, a correlation analysis was conducted to see whether or not salience of social identity with a workgroup or a project is related to time spent in the workgroup or the project (Hypothesis 5a and 5b). Table 2.7 shows the results of the correlation analysis. As shown in Table 2.7, the correlations were not statistically significant. In addition, nonlinear transformations such as power transformation and log transformation were used to test nonlinear relation between the time spent in a group and salience of social identity, but no significant correlation was observed. Therefore, Hypothesis 5a and 5b was rejected.

Table 2.7 Correlation between Workers tenure and Salience of Social Identity

Variables		**Workgroup**			**Project**		
		Cognitive Dimension	Affective Dimension	Evaluative Dimension	Cognitive Dimension	Affective Dimension	Evaluative Dimension
Tenure	*r*	.08	.06	.08	-.06	.15	-.06
	p	.50	.61	.46	.61	.17	.58

2.5 DISCUSSION

2.5.1 Theoretical and practical Implications

The analysis results show that despite the numerous recent efforts to improve workers' attitudes and behavior for safety in construction, workers' perceived group norms regarding safety behavior are still to some extent distant from the desirable attitudes. Based on these results, it can be argued that the current safety management programs need to be improved to better address the misalignment of norms regarding safety behavior between workers and project managers in construction. The findings of this study show that construction workers' safety attitudes were significantly influenced by group norms in spite of the transient and complex nature of the construction workforce. Therefore, it is inferred that socio-psychological approaches (e.g., programs to promote desirable perceptions and norms regarding safety behavior among workers) can significantly contribute to the improvement of construction safety. This suggestion is in line with recent results that workers' behavior is under the strong influence of social norms and culture, and therefore managerial approaches to promote desirable social norms among workers are required to improve worker behavior in construction projects (Ahn et al., 2013, 2014; Ahn and Lee, 2015). Additionally, the analysis results hint that construction workers' group norms are interrelated with their salient social identities, i.e., the groups with which construction workers most identify themselves, and feels pride and affection. Given the multiple and temporary nature of construction workers' identities, this finding implies both a challenge and an opportunity to improve workers' safety behavior in construction: construction workers' safety behavior will be better aligned with the behavior desired by project managers if they have salient project identity.

The fact that Hypothesis 2 was accepted confirms that a plausible reason for the misalignment between construction workers' personal standards and project managers' norms regarding safety behavior is that workers' personal standards regarding safety behavior are under a strong influence of the norms of their workgroups, which may be distant from the norms desired by project managers. The analysis results also show that the misalignment between construction workers' personal standards and project managers' norms existed in particular with respect to the actions that are uncertain in terms of the appropriateness (e.g., Action 2, 3, and 4), and that group norms significantly influence individual workers' attitudes regarding these actions. On the other hand, the misalignment was negligible for the obviously appropriate or inappropriate actions, such as Action 1 and 5.

An interpretation of these results finds that group norms might influence workers' interpretation (i.e., sense-making) of the actions that are uncertain in terms of appropriateness. The social identity theory supports this interpretation. It has been suggested that social behavior is motivated by a need to reduce uncertainty about one's perception of a behavior (Hogg, 2000). Certainty refers to one's confidence with how to behave in a certain situation (Hogg and Terry, 2000). Relying on others' evaluations (e.g., group norms) can provide increased confidence. This means that when a person is certain about the appropriateness of a behavior in a particular situation, he/she has fewer reasons to depend on others' evaluations. This idea is also supported by Festinger (1954)'s social comparison theory that asserted, "when objective, non-social basis for the evaluation of one's ability or opinion is readily available, persons will not evaluate their opinions or abilities by comparison with others." Therefore, it is implied that behavior-focused safety programs should help workers clarify by themselves which actions are appropriate, and which are not (i.e., injunctive norms). Once workers accept and internalize the norms, workers have reduced uncertainty about the appropriateness of behaviors, and produce the behavior better aligned with the norms, and when the norms are shared by a large number of members in workgroups, they become workers' new social norms in the project.

Additionally, the analysis results show that the trade identity and the workgroup identity were most salient, while the project identity was least salient in the construction workers. The social identity theory again lends an explanation for this observation. The salience of social identity is known to be determined by the interaction between accessibility of the category and fit between the category specification and a given situation (Oakes et al., 1991; Turner et al., 1994; Blanz, 1999). Accessibility refers to an individual's relative readiness to accept or activate a particular self-category in a given situation (Oakes et al., 1991; Stets and Burke, 2000). Construction workers usually work within a workgroup, and thus they frequently observe and interact with their workgroup members. Frequent interactions with group members mean that workers can easily retrieve the group membership in their minds. On the other hand, fit is defined as "the extent to which the social categories are perceived to reflect social reality" (Hornsey, 2008). Individuals would perceive a high level of fit if the category shows a high level of similarity within categories and difference between categories (Oakes et al., 1991; Turner et al., 1994; Hogg and Reid, 2006). Trade is a group of people who share the same skills and expertise. In addition, construction workers' work is strongly categorized and defined by their trade. Thus, construction workers may perceive a high level of similarity within their trade and sense a clear difference from other trades.

The observation of different salience levels associated with different identities has important implications for behavior-based safety management in construction According to social identity theory, the fact that the trade identity was most salient in construction workers implies that the chances are large that construction workers' safety attitude is influenced by the norms shared in the trade. Therefore, enhancing the safety-related programs within each trade that can affect construction workers' perception of safety norms might be an effective approach to improving workers' safety behavior. For example, safety training courses and programs from trades can include testimonials by people in the trade regarding safe and unsafe behaviors and their consequences. Such sources of information on safety behavior may be trusted more and regarded as more credible than the information coming from the company or other sources. On the other hand, the fact that the project identity was least salient in construction workers implies that the chances are small that construction workers' safety attitudes are influenced by the norms promoted by project managers. Therefore, it is conjectured that an increase in the project identity has to be pursued in order to improve the alignment of safety norms between the workers and the project managers.

The result of correlation analysis between the misalignment measure $M_i^{PS,PN}$ (i.e., the misalignment between one's personal standards and his/her perceived workgroup norms for the actions) and the salience of the workgroup identity demonstrated that an increase in the salience of the workgroup identity is associated with an enhanced alignment between workers' perceived group norms and their personal standards. In other words, this result presents a moderating effect of the salience of workgroup identity on the influence that the workgroup norms have on personal standards regarding safety behavior. Among the three dimensions of workgroup identity, in particular the affective dimension and the evaluative dimension of the workgroup identity had a statistically significant impact on the workgroup norms' influence on personal standards regarding safety behavior. An interpretation of this result is that if a worker is proud of or feels happy about his/her workgroup, they may be more willing to accept the workgroup norms. Although the cognitive dimension of social identity did not have direct impact on the workgroup norms' influence on personal standards in the data, it may have indirect impact mediated by the affective dimension and the evaluative dimension of social identity. Bergami and Bagozzi (2000) demonstrated an indirect effect of the cognitive dimension of social identity on workers' organizational citizenship behavior as mediated by the affective dimension and the evaluative dimension of social identity. Still, the complicated relationship between the three dimensions of a social identity is under investigation, and more research would be required to clearly demonstrate the impact of each of the three dimensions on the influence of group norms on construction workers' personal standards regarding safety behavior.

The fact that Hypothesis 5a and Hypothesis 5b were rejected suggests that a lengthy tenure at a workgroup or a project does not necessarily increase the salience of social identity with the group. In other words, it is not expected that construction workers will have an increased salience of social identity with a workgroup or a project only because they spent much time with the workgroup or the project. Given that the salience of a social identity is determined by the accessibility and fit of a group, accessibility and fit are not necessarily a function of time. Therefore, to increase the salience of the project identity in construction workers, and ultimately to make workers more likely to accept the safety behavior norms desired by project managers, project managers should be able to increase the accessibility and fit of the project identity. Social identity literature provides several ways to increase individuals' social identification with organizations, including emphasizing the distinctiveness of group, group prestige, and salient out-groups. These methods may be considered to increase workers' identity with a construction project. Moreover, these methods would be more effective if managers implement such interventions during the orientation/on-boarding processes for construction project personnel commencing at the site so that when they enter the project they can perceive that this project is different from others. However, the effectiveness of these methods has not been sufficiently demonstrated with empirical data, and more research is warranted to find the most suitable methods to increase the salience of the project identity in construction workers as a means of improving workers' safety attitudes and behavior. In this regard, the authors are currently conducting empirical studies to identify the impact of the managerial actions on workers' social identification with their project.

2.5.2 Methodological Merits

This study adapted a behavioral economic experiment (i.e., norm elicitation protocol) to quantify group norms regarding safety behavior. Most of the previous studies on social influence regarding an individual's behavior have used simple surveys (Brondino et al., 2012; Zhang and Fang, 2013; Bagozzi and Lee 2002), and this has been the case in most of the studies in construction safety as well. Although the survey method can be used to measure group norms in a cost-effective way, it is subject to response bias (Podsakoff et al. 2003). Specifically, if the questionnaire includes sensitive questions (such as asking about performing unsafe action in a certain situation), responses from direct questioning can be biased (Ganster et al. 1983; Mcfadden 2009). The incentivized coordination game structure in the norm elicitation protocol can reduce the possibility of such biases in the response (Burks and Krupka 2012).

2.5.3 Limitations and Future Directions

The study presented in this chapter has several limitations that can be addressed in future studies. First, this study did not take into account personal factors (e.g., personality) and environmental factors (e.g., work pressure, and site conditions) in the safety behavior context. The impacts of personal factors and environmental factors on workers' safety attitudes and behavior have been supported by a number of previous studies (Choudhry and Fang, 2008; Törner and Pousette, 2009; Fogarty and Shaw, 2010; Han et al., 2014). However, this study was not intended to include all factors that may influence workers' safety behavior. Rather, it focused on the effect of group norms and social identities on workers' safety behavior in order to expand understandings of socio-psychological aspect of safety behavior. The possible interactions of such socio-psychological factors with personal factors or environmental factors can be considered in future research.

Furthermore, this study did not consider different types and sources of social influence. Social norms are categorized into descriptive norms and injunctive norms (Deutsch and Gerard, 1955; Cialdini et al., 1991). Injunctive norms refer to perceptions of which behaviors are typically approved or disapproved by others, whereas descriptive norms refer to the perception of which behaviors are typically performed by others. Perceiving group norms by observation of coworkers' behaviors, which was the focus in this research, is an example of descriptive norms. However, project managers' feedback on workers' behavior can be one of the ways by which workers are influenced by injunctive norms. The literature indicates that workers' safety behavior can be affected by a number of different mechanisms, such as modeling of a superior's behavior, behavioral reinforcement, and incentivization (Fang et al. 2015). Furthermore, it is possible that the norms desired by project managers and workers' perception of the norms are misaligned due to miscommunication or misperception. Therefore, additional research efforts are required to investigate the effect of different sources and types of social norms on workers' safety attitudes and behavior in the future.

2.6 CONCLUSIONS

This chapter investigates the current status of different social norms regarding safety behaviors (i.e., workers' perceived group norms and managers' desired norms) and workers' social identities in construction projects. With the quantitative analysis results, it is concluded that: (1) there is a measurable difference between construction workers' perceived group norms and the norms desired by project managers regarding safety behavior—workers' attitudes regarding safety behavior are significantly more lenient than the norms desired by project managers; (2) construction workers' personal standards regarding safety behavior are significantly influenced by their perceived group norms; (3) construction workers identify themselves with different groups they belong to (e.g., union, trade, workgroup, company, and project) to significantly different degrees—the trade identity is most salient and the project identity is least salient in construction workers; (4) the salience of social identification with a group moderates the influence that the group's norms have on personal standards regarding safety behavior in construction workers; and (5) the amount of time spent on the current project was not significantly associated with the salience of social identification with workgroup or project.

The findings from this chapter suggest a new way of thinking about safety management in construction. Since social identification is involved with the process of genuine internalization of group norms rather than superficial compliance with them (Akerlof and Kranton, 2000; Hogg and Smith, 2007), the safety attitudes shaped by social identification would be a more durable and cost-effect way to improve worker's safety behavior. Therefore, managerial efforts to improve social identification with the project can be an effective means of improving workers' safety behavior in construction projects. In addition, it is expected that the results of this study will help construction organizations better understand the importance of the social influence on workers' behavior in general and contribute to developing more effective managerial actions and strategies for managing the construction workforce.

CHAPTER 3

THE ROLE OF SAFETY NORMS AND SOCIAL IDENTIFICATIONS IN CONSTRUCTION WORKERS' SAFETY BEHAVIORS[3]

3.1 INTRODUCTION

The previous chapter highlighted the misalignments between workers' perceived group norms and the norms desired by managers regarding safety behaviors. Related to this, a number of researchers recently have suggested that safety norms or safety climate may exist at multiple levels in an organization (Zohar 2000; Meliá et al. 2008; Jiang et al. 2010; Brondino et al. 2012; Kouabenan et al. 2015). Zohar (2000) suggested a two-level safety climate model which consists of organizational safety climate and group safety climate. Meliá et al. (2008) and Brondino et al. (2012) included co-workers as a safety climate component in addition to top-management and supervisors and showed that coworkers' safety climate mediated the relationship between safety climate and safety performance. Jiang et al. (2010) found that these two social influence mechanisms might work independently. All these findings demonstrate that workers' safety behavior would be influenced by their interaction with coworkers (e.g., observation of coworkers' behavior) as well as managers (e.g., feedback from managers about the appropriateness of behaviors related to safety).

Due to the temporary and contract-based nature of employment in construction projects, however, it is not yet very clear how and at which level of organization social norms are developed, and through which process social norms influence individual workers' safety behavior in

[3] This chapter is adopted from Choi, B., Ahn, S., and Lee, S. (2017) "Role of Social Norms and Social Identifications in Safety Behavior of Construction Workers. I: Theoretical Model of Safety Behavior under Social Influence." *Journal of Construction Engineering and Management*, 143(5), 04016124

construction. Most of the previous multi-level approaches assumed a permanent organization in which all the organizational members share a company identity as their common background, which helps to form and maintain coherent norms (Litwin and Stringer 1968; Tyagi 1982). However, the characteristics of organizational structures in construction make the effects of social norms on safety more complex (Lingard et al. 2010). In a construction project, it is plausible that managers from a general contractor and the construction workers in the same project may not share the company identity because often workers are not directly hired by a general contractor but hired by a subcontractor. Sharing the same identity plays an important role in forming and maintaining coherent safety norms among the project participants. According to the social identity theory, an individual's identification with the group is an important mechanism that moderates the effects of group norms on an individual's behavior (White et al. 2009). With this background, the previous chapter investigated the current status of safety norms and social identities in construction projects. However, currently it is still unclear how social norms are developed and through which process social norms influence individual workers' safety behavior in construction projects. To fill the knowledge gap, this chapter construct and test a theoretical model that explains the role of different social norms and social identities in construction workers' safety behavior.

3.2 THEORETICAL MODEL OF CONSTRUCTION WORKERS' SAFETY BEHAVIOR UNDER SOCIAL INFLUENCE

In this study, a theoretical model of construction workers' safety behavior under social influence is suggested based on related theories, and several hypotheses are tested in an attempt to address the aforementioned knowledge gaps. Figure 3.1 illustrates the proposed theoretical model. It should be noted that this model does not stipulate all factors of safety behavior, but has a particular focus on the process by which workers' social behavior is under the influence of social norms. Following is the description of the proposed theoretical model: Perceived management norm (X) affects safety behavior (Y) through perceived workgroup norm (M); The degree of the influence of perceived management norms and perceived workgroup norms on safety behavior is determined by the moderators (Vs) such as project identity and workgroup identity; Personal attitude (A) has its own direct influence on safety behavior; and Collective self-concept (Q), and nationality (U and K) are included as control variables. It should be noted that the proposed theoretical model only stipulates possible relationships between those variables, and does not necessarily mean that all the variables are significant for all situations. The hypotheses that can be derived from this model are discussed in the following sections.

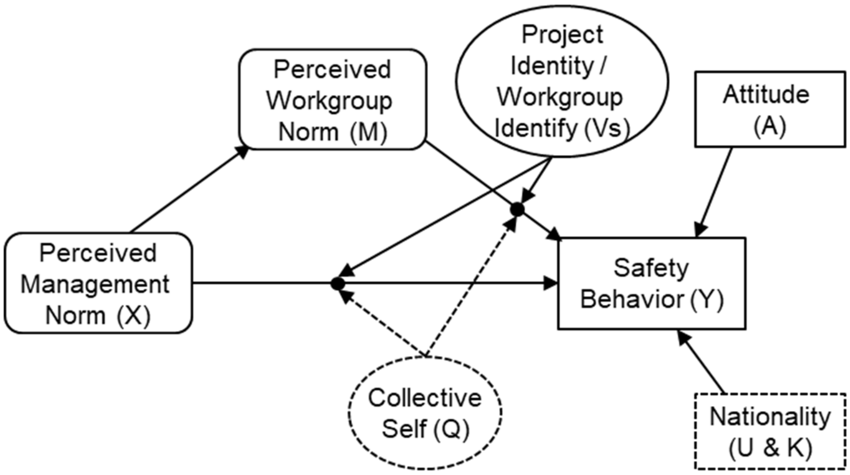


Figure 3.1 Theoretical Model for Social Influence on Workers' Safety Behaviors

3.2.1 The Influence of Perceived Management Norm and Perceived Workgroup Norm on Workers’ Safety Behaviors

As mentioned previously, workers’ safety behavior would be influenced by managers’ feedback on specific unsafe behaviors, which provides a chance for workers to learn about which kinds of behaviors managers believe to be appropriate (i.e., perceived management norm). As an example, if workers do not receive any feedback from managers even if they engage in some form of unsafe behavior, that behavior might be perceived as acceptable in the current project. Perceived management norms are formed in this manner and would be closely related to injunctive norms, which reflect perceptions of what others approve of or think one ought to do (Cialdini et al. 1991). On the other hand, workers can also perceive appropriateness of behaviors in a given situation by observing their coworkers’ behaviors (i.e., perceived workgroup norm). Perceived workgroup norms are formed in this manner would be closely related to descriptive norms, which reflect perceptions of what most others do (Deutsch and Gerard 1955; Cialdini et al. 1991).

According to Latané’s (1981) theory of social impact, the amount of social impact “should be a multiplicative function of the strength (i.e., salience, power, importance or intensity of a source to target), immediacy (i.e., closeness in space or time and absence of intervening barriers), and the number of other people." In a construction site, although managers have formal power in an organizational hierarchy, coworkers might also be an important source of social impact since workers perceive their coworkers as experts for their tasks (i.e., strength) (Andersen et al. 2015; Tucker et al. 2008; Lingard et al. 2011). In addition, since construction workers usually work in a team (i.e., crew or workgroup) and thereby share the identity of the workgroup, workers can be closer to their coworkers than to the managers in physical distance as well as psychological distance (i.e., immediacy). Moreover, coworkers are usually greater in number than managers in construction sites (i.e., the number of other people). Therefore, perceived workgroup norms are likely to be a more proximal antecedent of workers' safety behavior than perceived management norms. Also, perceived management norms can be seen as the safety norms of the project, and thus perceived management norm can serve as a reference frame for workers to use to evaluate their coworkers' safety behaviors in the project. In other words, coworkers' safety behaviors can be interpreted based on the perceived management norm in the current project. For example, workers can conceive that coworkers in the current project perform their task safely because managers indicate strict norms concerning safety behavior. This implies that perceived management norms can influence workers' safety behavior via perceived workgroup norms (i.e., perceived workgroup norm mediates perceived management norm). A number of previous studies have empirically demonstrated the mediation effect of workgroup norms on the relationship between organizational value and individuals' safety behavior (Zohar and Luria 2005; Meliá et al. 2008; Brondino et al. 2012). Based on these notions, it is hypothesized that perceived workgroup norms mediate the influence of perceived management norms on workers' safety behavior. Specifically, the following two hypotheses are constructed to examine the mediating effect of perceived workgroup norms on the relationship between perceived management norms and workers' safety behavior.

- Hypothesis 1a: *The perception of management norm predicts workers' perceived workgroup norm.*
- Hypothesis 1b: *The* perception *of workgroup norm predicts workers' safety behavior.*

3.2.2 The Role of Project Identity and Workgroup Identity in the Social Influence on Safety Behaviors

According to the social identity theory, individuals would characterize and situate themselves in a social environment by categorizing themselves and others into various social groups (i.e., a process formally referred to as 'self-categorization') (Ashforth and Mael 1989). In this self-categorization process, social groups are also associated with a prototype of the group; the prototype is abstracted from the attributes of the group members and is associated with a set of description and prescriptions of what being group member involves (Terry et al. 1999; Ellemers et al. 2002; Hogg and Reid 2006). The group norm reflects an individual's perception of a description and prescription of group members' behaviors (Turner et al. 1987; Bagozzi and Lee 2002; Hogg and Reid 2006; Smith and Louis 2009). The social identity theory states that when a particular group identity is salient, people tend to try to conform to the salient group's norm (Wood 2000; Smith et al. 2007; Smith and Louis 2008). Social identity theorists have identified this group norm internalization mechanism as a fundamental and basic way in which social identification affects behaviors. The internalization process essentially means that there are interactions between group norm and one's identity (Terry and Hogg 1996).

Since managers' feedback regarding workers' safety behavior would be perceived by workers as a project-level normative influence, according to the social identity theory the degree by which workers are affected by those perceived management norms would be determined by how strongly workers identify themselves with the project (namely, project identity). Therefore, it is hypothesized that workers' strong social identification with the project intensifies the influence of perceived management norms on their safety behavior. Several researchers have found that workgroup norms regarding safety tend not to be stricter than the management norm. Choudhry and Fang (2008) described the adverse effect of workgroup norm on safety behavior, and Andersen et al. (2015) found that there are conflicts between workgroup norms and management norms regarding appropriate safety behavior. Also, the previous chapter demonstrated that that the perceived workgroup norm tends to be more lenient regarding safety behavior than management norm. In this regard, workers in construction projects may not conform to managers' strict safety norms because their coworkers tell them to "work quickly in order to get the job completed rather than safely" (Mullen 2004). Therefore, if there are conflicts between the perceived management norm and the perceived workgroup norm, project identity might work such that the influence of the perceived workgroup norm becomes reduced while the influence of the perceived management norm is increased.

Based on findings that perceived workgroup norms and perceived management norms are distant, it is hypothesized that workers who highly identify themselves with the project demonstrate a stronger relationship between perceived management norms and safety behavior, and a diminished relationship between perceived workgroup norm and safety behavior. In addition, the influence of perceived workgroup norms on workers' safety behavior would be related to workers' identification with their workgroup. Therefore, it is also hypothesized that workers who highly identify themselves with their workgroup show a stronger relationship between perceived workgroup norms and safety behavior and a diminished relationship between perceived management norms and safety behavior. Specifically, the following four hypotheses are constructed.

- Hypothesis 2a: *The relationship between perceived management norm and safety behavior is stronger for workers with more salient project identity.*
- Hypothesis 2b: *The relationship between perceived workgroup norm and safety behavior is weaker for workers with more salient project identity.*
- Hypothesis 3a: *The relationship between perceived management norm and safety behavior is weaker for workers with more salient workgroup identity.*
- Hypothesis 3b: *The relationship between perceived workgroup norm and safety behavior is stronger for workers with more salient workgroup identity.*

3.2.3 The Role of Personal Attitude in Safety Behaviors

Workers' safety behaviors are affected by the combined influences of organizational and individual factors (Cooper 2000; Fang et al. 2015). To incorporate the factor of individuals' characteristics, this study includes personal attitude as a proximal antecedent of safety behavior. Attitude refers to "the degree to which a person has a favorable or unfavorable evaluation of the behavior in question" (Ajzen and Madden 1986). Attitude reflects "one's overall positive or negative evaluations on the behavior" (White et al. 2009). A number of studies have empirically supported the role of attitude in the predictions of various types of behavior (Armitage and Conner 2001; Johnson and Hall 2005; Goh and Sa'adon 2015). Since the relative importance of individual and organizational factors in the prediction of behavior varies across behaviors and situations (Ajzen 1991), attitude is included in this study as a predictor of safety behavior and the following hypothesis is constructed.

- Hypothesis 4: *Personal attitude predicts workers' safety behavior.*

3.2.4 Collective Self-Concept as a Control Variable

The model includes collective self-concept as a control variable in the social influence process. Recent research has distinguished three levels of self-definition, the individual, relational, and collective levels of self-concept (Brewer and Gardner 1996; Johnson et al. 2006). The individual level involves one's sense of uniqueness driven from the interpersonal comparison (Du et al. 2012). The relational level involves one's self-definition based on the relationships with others in specific contexts (Brewer and Gardner 1996). The collective level is based on the extent to which individuals define themselves in terms of group memberships (Johnson et al. 2006). When collective self-concept is activated, people are more likely to be influenced by social norms (Ybarra and Trafimow 1998). It implies that collective self-concept can also interact with group norms to influence an individual's behavior. In this regard, the distinction between collective self-concept and social identity is important. While the collective self-concept refers to the degree of an individual's general tendency to define oneself as a member of group, the social identity has a specific reference group with which he/she identifies (e.g., project identity and workgroup identity). Thus, this study includes the collective self-concept as a variable in order to control its effect in investigating the moderating effect of social identities on safety behavior.

3.3 METHODS

3.3.1 Participants and Procedure

A survey questionnaire was designed to measure the variables discussed in the theoretical model, and then a purposive sampling method was employed to collect data for the variables. Purposive sampling allows researchers to select cases that will be suitable for achieving the research objectives (Saunders et al. 2011). Due to the prevalent difficulty of obtaining a large number of and diverse samples in the construction domain, non-probability sampling, such as purposive sampling, has frequently been used in construction research (Abowitz and Toole 2009). However, an inclusion of samples from different regions and various types of construction projects were used in this study with an aim to increase diversity in the sample in terms of cultural backgrounds, organizational structure, and project types. In this sense, the sampling method used in this research is heterogeneous sampling among several different kinds of purposive sampling (Saunders et al. 2011). Heterogeneous sampling enables to collect data and explain the key themes that can be observed over the sample (Saunders et al. 2011). Patterns that emerge from the sample are likely to be of particular interest and can represent the key themes (Patton 2002).

The data were collected from eight construction sites in the U.S. (two sites), Korea (two sites), and Saudi Arabia (four sites) from June 2015 to September 2015. Among the eight sites, one is a research facility retrofit project, four are building construction projects (e.g., research facility, university dormitory, hospital, and office building), two are infrastructure construction projects (e.g., bridge and tunnel), and one is a waste water treatment facility renovation project. The study was approved by the Institutional Review Board (IRB) of the University of Michigan. Construction worker participants were recruited after establishing an agreement with the project managers to conduct the survey on their sites. One week prior to the survey, foremen on the sites were informed the purpose and process of the survey by research team members in a weekly meeting, and they verbally advertised the survey to their workgroup members. The survey was conducted in the conference room on each site at a prearranged time. 10 – 15 workers participated in the survey each time and 3 – 4 research team members administrated the survey. Before starting the survey, the administrators introduced the purpose and procedure of the survey as well as potential risk, and explained the meaning of the terms used in the questionnaire (e.g., workgroup – the group of people you work with as a team every day). Also, participants were provided with an informed consent form prior to participating and asked to sign if they agreed to participate. Questionnaires were completed anonymously, and the completed questionnaires were collected immediately by administrators to ensure the confidentiality of the responses. The survey took approximately 20-25 minutes in total to complete.

Total sample size was 284; 75 were from the U.S., 107 from Korea, and 102 from Saudi Arabia. The authors approached the three countries so that the sample has diversity in terms of cultural backgrounds and organizational structure. In terms of cultural backgrounds, Korea and Saudi Arabia are categorized as collectivistic cultures, and the U.S. is categorized as an individualistic culture (Hofstede Centre 2016). In terms of organizational structure, in the U.S. and Korean samples general contractors subcontracted a large portion of contract work, but in participants in the Saudi Arabian sites were engaged in the direct hiring of workers. Despite these differences, all participants in this study were field workers who would move to other projects after completing their own task in the current project. Based on such shared attributes of the samples in this study, the entire data set is used to test the proposed explicative model of social influence on construction workers' safety behavior. In the meantime, nationality is included as a control variable in this study in order to control its direct effect on safety behavior. Of all participants, 26% are younger than 30 years old, 19% are between 31 and 40 years old, 28% are between 41 and 50 years old, and 27% are older than 50 years old. In terms of construction industry experience, 29% have less than 5 years experience, 26% have 5 -10 years experience, 19% have 10-15 years experience, and the rest 26% have more than 15 years of experience in the field. Approximately 57% of the entire samples have worked for less than 6 months, and 32% have worked 6 months - 1 year, and the rest 11% have worked for more than 1 year in the current project. As mentioned before, workgroup in this study was defined as a group of people the participant work with as a team on a daily basis, and the size of the workgroups in this study varied from three to fifteen.

3.3.2 Measures

Measures for the variables in this study are shown in Table 3.1. Before testing the model, the adequacy of the measures was assessed based on reliability (i.e., Cronbach's alpha) as well as convergent and discriminant validity in order to demonstrate the validity of the questionnaire items, and the results of these tests, such as factor loadings, reliabilities (i.e., Cronbach alpha), critical ratios (CRs), and average variance extracted (AVEs), are presented as well in Table 3.1. Respondents responded to a series of 7-point Likert scale items listing options from "Strongly Disagree" (-3) to "Strongly Agree" (3). Prior to the actual survey administration, a pilot study was conducted with eight field workers using the draft questionnaire, and several rounds of improvements on the measures and instructions were made. In the survey questionnaire, perceived management norms were operationalized as managers' reaction to a worker's safety-related behavior in a specific situation expected by the respondent. Three hypothetical but plausible situations (i.e., stop working with no anchor point to tie off to, wearing uncomfortable safety glasses, and connecting snap hook in no perceived danger of falling) were used to measure perceived management norm. Each of these three items represents a dilemma situation, in which worker's self-interest (e.g., efficiency of task performance) conflicts with safety requirement. Therefore, in this kind of situation workers might not be entirely certain regarding which behavior is most appropriate and/or desirable, and might choose whichever "makes more sense" to them. More specifically, these questionnaire items were devised to measure strictness, which is defined as the degree by which a safety requirement is not compromised for any reason. This kind of survey technique involving respondents' choice in dilemma situations has been widely used in morality research, such as Kohlberg Questionnaire (Kohlberg 1984). An example of the items used in our questionnaire is, "Managers on this project think that I should stop working if there is no anchor point to tie off when I am working on a surface 6 feet or more above the ground." Since the regulation states that workers should ensure that they are tied to an anchor point when they are working on a surface 6 feet or more above the ground, selecting a higher scale option for this question (e.g., Strongly Agree (3)) would mean that the perceived management norm is stricter in that regard. Similarly, perceived workgroup norm is measured by three questions that reference workers' observation of their coworkers' behavior in the same situation. In the questionnaire items, the perceived workgroup norm is operationalized as his/her coworkers' actions in a given situation expected by the respondent. In other words, selecting a higher scale option for this question (e.g., Strongly Agree (3)) would mean that the perceived workgroup norm is stricter in that regard.

In the questionnaire, nine items adopted from Ellemers et al. (1999) and Bagozzi and Lee (2002) are used to measure the strength of identification with project or with workgroup in three dimensions: cognitive ("a cognitive awareness of one's membership in a social group"), affective ("a sense of emotional involvement with the group"), and evaluative dimension ("a positive and negative value connotation attached to the group membership"). Attitude is measured by four evaluative semantic differential scales from White et al. (2009). Positive semantic scales (i.e., pleasant, advantageous, useful, and favorable) have a higher scale value in the questionnaire, and thus a higher scale value reflects positive attitudes toward safety rules. Three items from Johnson et al. (2006) are used to measure collective self-concept in this study. In addition to the constructs included in the theoretical model, this study also measures workers' own opinions about the same situations that were used to measure perceived workgroup norm and perceived management norm, in order to separately identify perceived workgroup norm, perceived management norm, and workers' own opinions regarding safety behavior. An example of the items used to identify a worker's own opinion is "I intend to stop my work if I cannot find an anchor point to tie off when I am working a surface 6 feet or above the ground".

Table 3.1 Measures, Factor Loadings, and Reliabilities

Variables	Items	Factor loadings	CR	Reliability (α)	AVE
Perceived management norm	• Managers on this project think that I should stop working if there is no anchor point to tie off when I am working on a surface 6 feet or more above the ground.	.70	-	.81	.57
	• Managers on this project think that I should always wear safety glasses when I am exposed to flying fragments and particles, even if safety glasses impede my peripheral vision (e.g., fogging, scratching, and blurry lenses).	.70	12.85		
	• Managers on this project think that I should always connect my snap hook to an anchor point when I am working on a surface 6 feet or more above the ground, even if it seems there is no danger of falling.	.85	16.49		
Perceived workgroup norm	• My crew members stop their work if they cannot find an anchor point to tie off when they are working on a surface 6 feet or more above the ground.	.69	-	.73	.49
	• My crew members always wear safety glasses when they are exposed to flying fragments and particles, even if safety glasses impede peripheral vision (e.g., fogging, scratching, and blurry lenses).	.58	10.07		
	• My crew members always connect their snap hook to an anchor point when they are working on a surface 6 feet or more above the ground, even if they do not perceive any danger of falling.	.82	15.30		
Project identity	• Cognitive dimension • (e.g. I am similar to other members in this project.)	.70	-	.83	.62
	• Affective dimension • (e.g. I am happy to be a member of this project.)	.84	17.42		
	• Evaluative dimension • (e.g. I am a valuable member of this project.)	.78	15.02		

Variables	Items	Factor loadings	CR	Reliability (α)	AVE
Workgroup identity	• Cognitive dimension • (e.g., Being a member of my crew is an important part of who I am.)	.69	-	.83	.63
	• Affective dimension • (e.g., I feel strong sense of belonging to my crew.)	.83	16.35		
	• Evaluative dimension • (e.g., To me, being a member of my crew is an important source of self-esteem.)	.84	16.49		
Safety behavior	• I always connect my snap hook to an anchor point when I am working on surfaces 6 feet or more above the ground.	.84	-	.75	.53
	• I always wear safety glasses when I am exposed to flying fragments and particles	.78	14.77		
	• I do not take any short cut even if I am under time pressure.	.52	8.86		
Attitude	• Very Unpleasant – Very Pleasant	.60	-	.79	.49
	• Very Disadvantageous – Very Advantageous	.66	11.29		
	• Very Useless – Very Useful	.67	11.61		
	• Very Unfavorable – Very Favorable	.82	14.91		
Collective self-concept	• Making a lasting contribution to groups that I belong to is very important to me.	.83	-	.81	.58
	• I feel great pride when my team or group does well, even if I am not the main reason for its success.	.74	13.59		
	• When I am involved in a group project, I do my best to ensure its success.	.72	13.10		

Note: CR (Critical Ratio), AVE (Average Variance Extracted)

3.3.3 Analytical Procedure

This study applied Hayes's (2013) PROCESS macro to test the hypotheses, because it provides the bootstrap results of the conditional effect of independent variables on the dependent variable, which is useful to make a statistical inference about the moderation effect. As shown in Figure 3.1, the mediating effect of the perceived workgroup norm occurs when perceived management norm (X) influences perceived workgroup norm (M), and perceived workgroup norm (M) in turn influences safety behavior (Y). The moderating effect occurs when the moderator variables (Vs) (i.e., project identity or workgroup identity) interact with perceived management norm (X) or perceived workgroup norm (M) in influencing on safety behavior (Y). The mediation and moderation effects illustrated in Figure 3.1 can be expressed in two equations. Equation (1) represents the effect of perceived management norm (X) on perceived workgroup norm (M).

Equation (2) represents the effect of perceived management norm (*X*) and perceived workgroup norm (*M*) on safety behavior (*Y*) with the interaction effect of a moderator (*V*). Also, attitude (*A*) is included in Equation (2) as an additional antecedent of safety behavior. Collective self-concept (*Q*) and nationality (*U* and *K*) are also included in Equation (2) as control variables.

$$M = \beta_{10} + \beta_{11}X + \varepsilon_1 \ \ldots\ldots \ (1)$$

$$Y = \beta_{20} + \beta_{21}X + \beta_{22}M + \beta_{23}V + \beta_{24}Q + \beta_{25}A + \beta_{26}XV + \beta_{27}MV + \beta_{28}XQ + \beta_{29}MQ + \beta_{30}U + \beta_{31}K + \varepsilon_2 \ \ldots\ldots \ (2)$$

The mediating effect of perceived workgroup norm (*M*) is demonstrated if β_{11} in Equation (1) and β_{22} in Equation (2) are significant. Also, the interaction effect of moderator (*V*) and perceived management norm (*X*) is demonstrated if β_{26} in Equation 2 is significant. The interaction effect of moderator (*V*) and perceived workgroup norm (*M*) is demonstrated if β_{27} in Equation 2 is significant. In the regression analyses, all variables are mean centered and interaction terms are calculated using the centered values in order to minimize the multicollinearity issue (Aiken and West 1991).

3.4 RESULTS

3.4.1 Measurement Assessment

Before testing the hypotheses, a confirmatory factor analysis (CFA) was performed to assess the adequacy of the measures used in this study by using LISREL 8.8. A CFA model with 7 latent constructs (i.e., perceived management norm, perceived workgroup norm, project identity, workgroup identity, attitude, collective self-concept, and safety behavior) and 24 measures was built, and this model fits the data satisfactorily. The goodness-of-fit statistics for the model are as follows: $\chi^2(187) = 446.87$, root mean square error of approximation (RMSEA) = .070, standardized root mean square residual (SRMR) = .048, non-normed fit index (NNFI) = .96 and comparative fit index (CFI) = .97. Factor loadings, critical ratio (CR), reliability, and average variance extracted (AVE) are presented in Table 1. As shown in Table 3.1, reliabilities for all constructs range from .73 to 83, which are usually considered satisfactory (Nunnally 1978). Also, convergent validity is established because the CFA model fits well, and factor loadings are high and significant (Bagozzi and Yi 1988). Discriminant validity is established if the correlations among the latent variables are significantly less than 1.00 (Bagozzi and Yi 1988). 95% confidence intervals for each correlation coefficient are constructed, and none of the confidence intervals includes 1.00. Therefore, discriminant validity is also achieved for all the constructs used in this study. Therefore, given the satisfactory level of reliability as well as convergent and discriminant validity, the measurement items used in this study can be seen adequate and usable for testing the research hypotheses.

3.4.2 Descriptive Statistics and Correlation

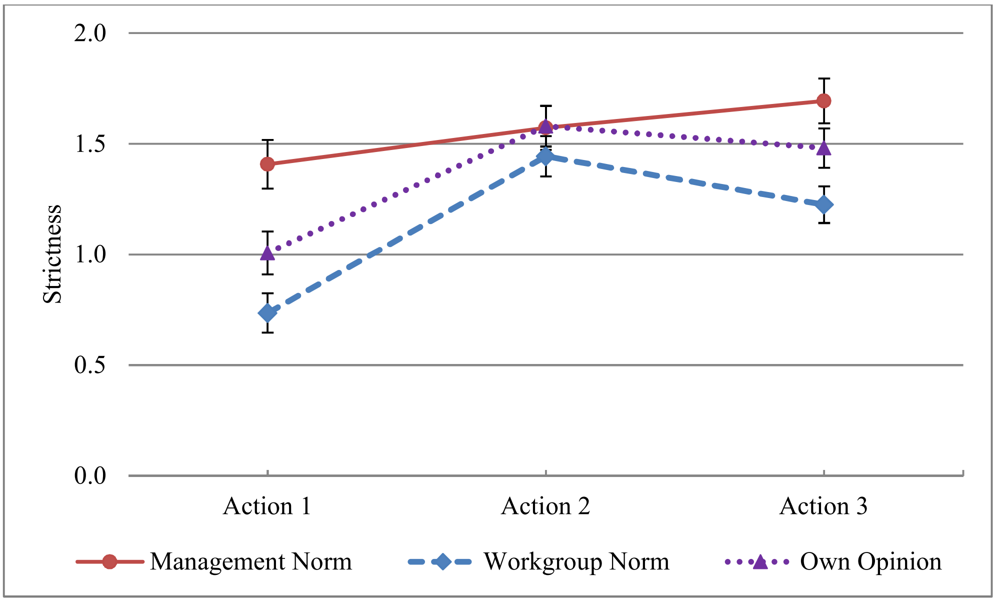
Table 3.2 shows the descriptive statistics and inter-correlation coefficients of the variables as well as demographic variables. Table 3.2 shows that perceived management norm, perceived workgroup norm, and attitude are significantly correlated with safety behavior with correlation coefficient ranging from .29 to .54. It indicates that workers who show stricter perceived management norms, perceived workgroup norms, and a more positive attitude demonstrate stricter safety behaviors. Also, the correlation coefficients among project identity, workgroup identity, and collective self-concept are significant and ranged from .59 to .70. The strong correlations among these variables justify the inclusion of collective self-concept as a control variable of the moderating effect of project identity and workgroup identity. In the correlation results, working experience has a significant negative correlation with safety behavior. Therefore, working experience is also included as a control variable in the following analyses.

Table 3.2 Descriptive Statistics and Correlation Coefficients

Variable	M	SD	Age	EXP	TEN	MN	WN	CS	PI	WI	ATT	BEH
Age	41.33	11.83	1.00	-	-	-	-	-	-	-	-	-
Working experience	11.81	8.37	.508**	1.00	-	-	-	-	-	-	-	-
Tenure	6.84	5.49	-.116	.088	1.00	-	-	-	-	-	-	-
Perceived management norm	1.56	1.26	.016	-.049	-.054	1.00	-	-	-	-	-	-
Perceived workgroup norm	1.13	1.40	-.088	-.156**	.023	.689**	1.00	-	-	-	-	-
Collective self-concept	1.85	1.02	-.148*	-.086	.048	.501**	.408**	1.00	-	-	-	-
Project identity	1.09	1.08	-.032	-.103	.081	.443**	.473**	.593**	1.00	-	-	-
Workgroup identity	1.40	1.01	-.085	-.039	.091	.352**	.347**	.597**	.669**	1.00	-	-
Attitude	1.44	1.08	-.016	-.159**	-.062	.225**	.253**	.280**	.301**	.308**	1.00	-
Safety behavior	1.53	1.19	-.021	-.167**	-.006	.515**	.539**	.515**	.455**	.337**	.291**	1.00

Note: N = 284, ATT (Attitude), BEH (Safety behavior), CS (Collective self-concept), EXP (Working experience), MN (Perceived management norm); PI (Project identity), TEN (Tenure), WI (Workgroup identity), and WN (Perceived workgroup norm), *$p < .05$, **$p < .01$

Figure 3.2 shows a graphical representation of the mean of perceived management norm, perceived workgroup norm, and workers' own opinions. In Figure 3.2, the horizontal axis refers to the three actions that are used to measure perceived management norm, perceived workgroup norm, and one's own opinion, and the vertical axis represents strictness of the norms. As shown in Figure 3.2, the perceived management norm tends to be stricter than the perceived workgroup norm, and workers' own opinion stands between perceived management norms and perceived workgroup norms. This pattern is line with the findings from the previous chapter that management norms and workgroup norms might not be aligned, and the management norm is likely to stricter than the workgroup norm (cf. Hypothesis 2 and 3). In order to statistically compare the strictness of perceived management norms and perceived workgroup norms, paired-samples t-tests were conducted for the three actions. The results of the paired-sample t tests marginally confirm the descriptive analysis results. For action 1 and action 3, there are significant differences in strictness between perceived management norms (action 1: M = 1.41, SD = 1.51, action 3: M = 1.69, SD = 1.40) and perceived workgroup norms (action 1: M = 0.72, SD = 1.84, action 3: M = 1.22, SD = 1.70); action1: t (281) = 6.95, p = .000, action 3: t (283) = 5.53, p = .000. However, the difference (i.e., wearing uncomfortable safety glasses) is not significant for action 2; t (282) = 1.59, p = .11.



Note: Mean with standard error

Figure 3.2 Management Norm, Workgroup Norm, and Workers' Own Opinion

3.4.3 Results of Hypothesis Testing

As shown in Table 3.3, the perceived management norm is a significant predictor of perceived workgroup norm (β_{11} = .69, t = 15.98, p < .000). Also, perceived workgroup norm is a significant predictor of safety behavior (β_{22} = .20, t = 3.53, p < .000). As discussed earlier, the condition to establish the mediating effect is that both β_{11} in the prediction of perceived workgroup norm and β_{22} in the prediction of safety behavior are significant. Because both β_{11} and β_{22} are significant, the hypothesized mediation effect is demonstrated. Therefore, H1a (i.e., The perception of management norm predicts workers' perceived workgroup norm.) and H1b (i.e., The perception of workgroup norm predicts workers' safety behavior.) are supported. Also, the analysis shows that the perceived management norm has significant influence on safety behavior even after controlling the effect of the perceived workgroup norm, because the interaction effects between perceived management norms and project identity (*β_{27}* = .20, *t* = 1.93, *p* = .050), and between perceived management norms and collective self-concept (*β_{29}* = -.21, *t* = -2.12, *p* = .035) on safety behavior are also significant; therefore, perceived workgroup norms partially mediates the relationship between perceived management norms and safety behavior.

In addition, perceived management norm (*X*) and project identity (*V*) interact significantly to influence safety behavior (*β_{27}* = .20, *t* = 1.93, *p* = .050). This demonstrates that project identity positively moderates the relationship between perceived management norms and safety behavior. In other words, those workers who hold more salient project identity tend to show stronger association between perceived management norm and safety behavior. Therefore, H2a (i.e., The relationship between perceived management norm and safety behavior is stronger for workers with higher project identity levels) can be supported. In addition, there is also a significant interaction effect between project identity and perceived workgroup norms (*β_{28}* = -.35, *t* = -3.75, $p < .000$) on safety behavior. The negative regression coefficient implies that the relationship between perceived workgroup norms and safety behavior are negatively moderated by project identity. This result is consistent with H2b (i.e., The relationship between perceived workgroup norms and safety behavior is weaker for workers with higher project identity levels) in that the influence of perceived workgroup norms on safety behavior would be diminished for workers who have a stronger project identity than those with a weaker project identity.

Table 3.3 Model for Project Identity as a Moderator Variable

Prediction of perceived workgroup norm (M) $\beta_{10} + \beta_{11}X + \varepsilon_1$

Variable	b	β	S.E	R^2	F
Perceived Management Norm (X) - β_{11}	.770**	.689**	.048	.475	255.44

Prediction of safety behavior (Y)
$= \beta_{20} + \beta_{21}X + \beta_{22}M + \beta_{23}V + \beta_{24}Q + \beta_{25}A + \beta_{26}C + \beta_{27}XV + \beta_{28}MV + \beta_{29}XQ + \beta_{30}MQ + \beta_{31}U + \beta_{32}K + \varepsilon_2$

Variable	b	β	S.E	R^2	F
Perceived Management Norm (X) - β_{21}	.117	.123	.070	.477	20.65
Perceived Workgroup Norm (M) - β_{22}	.200**	.236**	.057		
Project Identity (V) - β_{23}	.054	.050	.069		
Collective Self (Q) - β_{24}	.257**	.220**	.072		
Attitude (A) - β_{25}	.157**	.143**	.055		
Experience (C) - β_{26}	-.011	-.076	.007		
Perceived Management Norm x Project Identity (XV) - β_{27}	.133*	.202*	.069		
Perceived Workgroup Norm x Project Identity (MV) - β_{28}	-.239**	-.350**	.064		
Perceived Management Norm x Collective Self (XQ) - β_{29}	-.143*	-.214*	.067		
Perceived Workgroup Norm x Collective Self (MQ) - β_{30}	.082	.107	.066		
U.S. (U) - β_{31}	-.015	-.006	.168		
Korea (K) - β_{32}	.068	.028	.138		

Note: N = 284, *p < .05, **p < .01

Given the significant interaction between project identity and social norms (i.e., both perceived management norm and perceived workgroup norm), it would be worthwhile to investigate the conditional effects of perceived management norms and perceived workgroup norms on safety behavior depending upon different salience of project identity. To achieve it, the authors divided project identity into three levels: the mean (0) meaning project identity = 1.09, one standard deviation above the mean (+1SD) meaning project identity = 2.17, and one standard deviation below the mean (-1SD) meaning project identity = -.01. In order to control the influence that collective self-concept has on the moderating effect, the conditional effects were also examined at three different values of collective self-concept: the mean (0) meaning collective self-concept = 1.85, one standard deviation above the mean (+1SD) meaning collective self-concept = 2.87, and one standard deviation below the mean (-1SD) meaning collective self-concept = .83.

Table 3.4 shows the estimated effects of perceived management norms and perceived workgroup norms on safety behavior and the bootstrap confidence interval of the effects in each condition. The use of the bootstrap confidence interval is helpful to make a statistical inference about the conditional effects because it provides a range of estimated values with a certain confidence level (e.g., 95% or 99% confidence interval) (Hayes 2013). As shown in Table 3.4, in the -1SD and 0 collective self-concept conditions (i.e., not strong collective self-concept), effects of perceived management norm on safety behavior are statistically significant at 95% confidence interval (CI) at which project identity is +1SD (i.e., strong project identity), because the 95% CIs of the effect of perceived management norm do not include zero (i.e., collective self-concept = -1SD: .11 ~ .71, collective self-concept = 0: .05 ~ .48). However, the effects of the perceived management norm on safety behavior are not significant at which project identity is -1SD (i.e., weak project identity), because the 95% CIs straddles zero (i.e., collective self-concept = -1SD: -.02 ~ .26, collective self-concept = 0: -.21 ~ .16). These results demonstrate that the effect of perceived management norm on safety behavior would be greater when project identity is stronger. However, in the +1SD collective self-concept condition (i.e., strong collective self-concept), all effects of perceived management norm are not statistically significant at 95% CI, because the 95% CIs straddle zero (i.e., project identity = -1SD: -.46 ~ .12, project identity = 0: -.23 ~ .17 and project identity = +1SD: -.08 ~ .31), even if the estimated effects increase as the project identity increases.

On the other hand, the effects of perceived workgroup norms on safety behavior are statistically significant at 95% confidence interval (CI) at which project identity is -1SD, because 95% CIs do not include zero (i.e., collective self-concept = -1SD: .24 ~ .51, collective self-concept = 0: .30 ~ .62, and collective self-concept = +1SD: .28 ~ .80). However, the effects are not significant at +1SD project identity, as shown in Table 4 (i.e., collective self-concept = -1SD: -.42 ~ .14, collective self-concept = 0: -.25 ~ .13, and collective self-concept = +1SD: -.14 ~ .19). This indicates that the effect of perceived workgroup norm on safety behavior is greater when project identity is weak rather than strong.

Table 3.4 Conditional Effects of Perceived Management Norm and Perceived Workgroup Norm on Safety Behavior

Collective self (Q)	Project identity (V)	Perceived management norm			Perceived workgroup norm		
		Effects	95% CI		Effects	95% CI	
Q = -1SD (-1.02)	V = -1SD (-1.08)	.118	-.024	.260	.375	.237	.513
	V = 0 (0.00)	.262	.078	.445	.117	-.056	.290
	V = +1SD (+1.08)	.405	.105	.706	-.142	-.421	.137
Q = 0 (0.00)	V = -1SD (-1.08)	-.027	-.213	.159	.458	.297	.620
	V = 0 (0.00)	.117	-.020	.254	.200	.089	.311
	V = +1SD (+1.08)	.260	.046	.475	-.059	-.247	.130
Q = +1SD (+1.02)	V = -1SD (-1.08)	-.172	-.464	.120	.542	.280	.803
	V = 0 (0.00)	-.028	-.228	.172	.283	.110	.456
	V = +1SD (+1.08)	.115	-.080	.310	.024	-.144	.193

Then, the same procedure as above was repeated to examine the moderation effect for workgroup identity. The results from PROCESS analysis are presented in Table 3.5. First, it is examined whether perceived workgroup norm has a mediation effect on the relationship between perceived management norms and safety behavior when workgroup identity is the moderator. As shown in Table 3.5, because both regression coefficients (β_{11} = .69, t = 15.98, p < .000, β_{22} = .29, t = 4.43, p < .000) are significant, the mediation effect for the perceived workgroup norm is demonstrated. Therefore, H1a (i.e., The perception of management norm predicts workers' perceived workgroup norm.) and H1b (i.e., The perception of workgroup norm predicts workers' safety behavior.) can also be supported when workgroup identity is the moderator. However, there are no significant interaction effects between workgroup identity and perceived management norms (β_{27} = .02, t = .22, p = n.s.) and between workgroup identity and perceived workgroup norms (β_{28} = -.03, t = -.29, p = n.s.) on safety behavior. Therefore, H3a (i.e., The relationship between perceived management norms and safety behavior is weaker for workers with higher workgroup identity levels) and H3b (i.e., The relationship between perceived workgroup norms and safety behavior is stronger for workers with higher workgroup identity levels) are not supported.

Table 3.5 Model for Workgroup Identity as a Moderator Variable

Prediction of perceived workgroup norm (M) $= \beta_{10} + \beta_{11}X + \varepsilon_1$

Variable	b	β	S.E	R^2	F
Perceived Management Norm (X) - β_{11}	.770**	.689**	.048	.475	255.44

Prediction of safety behavior (Y)
$= \beta_{20} + \beta_{21}X + \beta_{22}M + \beta_{23}V + \beta_{24}Q + \beta_{25}A + \beta_{26}C + \beta_{27}XV + \beta_{28}MV + \beta_{29}XQ + \beta_{30}MQ + \beta_{31}U + \beta_{32}K + \varepsilon_2$

Variable	b	β	S.E	R^2	F
Perceived Management Norm (X) - β_{21}	.108	.114	.071	.447	18.22
Perceived Workgroup Norm (M) - β_{22}	.246**	.290**	.057		
Workgroup Identity (V) - β_{23}	-.045	-.038	.070		
Collective Self (Q) - β_{24}	.305**	.261**	.076		
Attitude (A) - β_{25}	.146*	.133*	.058		
Experience (C) - β_{26}	-.010	-.069	.007		
Perceived Management Norm x Workgroup Identity (XV) - β_{27}	.013	.020	.059		
Perceived Workgroup Norm x Workgroup Identity (MV) - β_{28}	-.020	-.025	.068		
Perceived Management Norm x Collective Self (XQ) - β_{29}	-.057	-.085	.060		
Perceived Workgroup Norm x Collective Self (MQ) - β_{30}	-.081	-.105	.062		
U.S. (U) - β_{31}	-.055	-.020	.163		
Korea (K) - β_{32}	.023	.009	.139		

Note: N = 284, *p < .05, **p < .01

Finally, the effects of attitude on safety behavior were tested. As shown in Tables 3.3 and 3.5, attitude is a significant predictor of safety behavior. A significant direct effect of attitude on safety is found when project identity is the moderator (β_{25} = .14, t = 2.85, p = .005) as well as when workgroup identity is the moderator (β_{25} = .15, t = 2.54, p = .012). This result demonstrates that positive attitudes toward safety rules lead to more desirable safety behavior. Therefore, H4 (i.e., Personal attitude predicts workers' safety behavior) can be supported.

3.5 DISCUSSION

3.5.1 Theoretical Implication

The results of this chapter add support to the growing evidence base around the role of social influence in construction safety (e.g., impact of perceived management norm and perceived workgroup norm). Specifically, it was found that the perceived workgroup norm would mediate the impact of the perceived management norm on safety behavior. This knowledge of the mediation effect is important because it allows us to understand the process through which social norms influence workers' safety behavior and reduce the risk of accidents. This chapter also shows the current status of construction safety by comparing perceived management norms, perceived workgroup norms, and workers' own opinions. The result shows that the perceived management norm is significantly stricter than the perceived workgroup norm, and workers' own opinion stands between perceived management norms and perceived workgroup norms, in the sample. This result provides several ideas regarding how construction workers would make sense of social norms. First, strict perceived management norms can exert forces to drag workers' own opinion toward the desirable direction in Figure 3.2. On the other hand, lenient perceived workgroup norms can exert forces to drag workers' own opinions down toward the undesirable direction in Figure 3.2. In simpler words, construction workers might not intend to perform unsafe behaviors because they will receive feedback from their managers. However, they do not fully follow the perceived management norm because the level of their coworkers' safety behavior is below the perceived management norm. Therefore, strengthening workers' willingness to adhere to perceived management norms would be an effective way to improve their safety behavior. Conflicts between management and workgroup to elicit workers' desirable behavior in construction projects are not only found in the safety behavior context but also in other behavior contexts such as absence behavior (Ahn et al. 2013). Ahn et al. (2013) demonstrated that "formal rule" which is established by management exerts a force to reduce workers' absence rate but "social adaptation" from coworkers' behavior exerts a force to increase workers' absence rate. In this study, workers' absence behavior was determined by dynamics between the two forces (i.e., formal rule and social adaptation). Although the formal rule in Ahn et al. (2013) is not the same with perceived management norm in this study, they are similar in a sense that they are from management. Therefore, given these consistent patterns between management and workgroup in different behavior contexts, it is expected that strengthening workers' willingness to adhere to perceived management norm could have effect beyond safety behavior and spillover into other types of behaviors.

This chapter contributes to existing construction safety research by investigating the effect of the interaction between social identity (i.e., project identity and workgroup identity) and social norms (i.e., perceived management norm and workgroup norm) on workers' safety behavior.

Although previous research efforts provided a number of empirical evidences on the direct effect of social norms on safety behavior, little attention has been paid to the interaction effect. The results of this study showed that construction workers' social identification with their project moderates the effect of perceived management norms and perceived workgroup norms on their safety behavior. This finding suggests that social influence on workers' safety behavior can be explained by the norm internalization process as driven by social identification.

3.5.2 Managerial Implications

The results of this chapter suggest several practical implications for safety management in construction projects. First, the analysis results tell us that promoting positive social norms can contribute to the amelioration of construction safety in spite of the temporary and itinerant nature of construction projects. This is especially important in such a typical construction project where most workers are temporarily hired through subcontractors. In this regard, not only safety managers but also other managers and engineers who interact with workers, such as superintendents and field engineers, would need to be careful for providing consistent feedback regarding workers' behaviors because inconsistent safety feedback among the managers in the same project can cause reduced influence of management norms. It would be also important for all managers to keep in mind that neglecting one worker's unsafe behavior can weaken the influence of management norms on other workers' safety behavior. In addition, managers would need to try to make workers aware of good examples of coworkers' safety performance. In practice, public rewards for exemplary safety behavior in tool-box talks can be a great way to remind workers of the presence of favorable workgroup norms. On the other hand, managers might need to be cautious about publicly making comments on workers' unsafe behavior. This is because although such a public comment can make workers more aware of inappropriate behavior, at the same time there is a risk that workers perceive the prevalence of undesirable workgroup norms.

Second, the presence of the moderating effect of project identity on social influence process suggests that project identity can intensify the positive impact of perceived management norms and attenuate the negative impact of unfavorable perceived workgroup norms on safety behavior. Despite the potential of project identity to improve workers' safety behavior, project identity is the weakest among several existing identities in construction workers (e.g., trade, company, workgroup, union, and project) as shown in the previous chapter. This suggests that managers should try to strengthen workers' project identity. Previous studies proposed several effective strategies to increase individual's social identity. First of all, symbolic management using physical markers such as uniforms, badges, and logos has a strong influence on the development of a social identity. (Pratt and Rafaeli 1997; Worchel et al. 1998; Postmes 2003). Second, communication among group members can also be an effective way to enhance individuals' social identity (Underwood et al. 2001; Scott 2007). For example, private conversation about group membership can strengthen the group identity (Haslam et al. 1999). Third, public statements of group adhesion—even if not spontaneous—can have a strong influence on an individual's group identity and their performance (Postmes 2003). These strategies can be considered in construction projects as a means of fostering workers' social identification with project, and ultimately improving workers' safety behavior.

3.5.3 Limitations and Future Direction

Although this study helps advance our understanding of how social norms and social identification affect workers' safety behavior, there are several limitations of the study. First of all, this study did not distinguish construction managers belonging to different companies. Managers in a construction project can be divided into managers from a general contractor and from a subcontractor. Each company (i.e., general contractor and subcontractor) might have their own organizational goals and values as well as safety policies, procedures, and practices. In a construction project, usually the general contractor establishes project-level safety policies and procedures, and subcontractors implement the safety policies and procedures with a certain level of discretion. A project manager from each subcontractor, therefore, might have different social norms regarding safety behavior from a project manager from the general contractor. Therefore, more research efforts are required to consider possible misalignments of social norms across different organizational levels.

Second, the results of this chapter are derived from a cross-sectional design, which has limitations in explaining the dynamic relationships among the variables. Specifically, cross-sectional study is limited to exploring the ramification of reciprocal determinism (McAuley and Blissmer 2000), which means the bidirectional influence between worker behavior and perceived workgroup norms in the context of this research. Although cross sectional designs are common in safety research and are acceptable in the initial stages of the research (Cigularov et al. 2010), longitudinal studies can be used in future studies to clarify the causal relationship.

Lastly, variables in this study were measured based on perceptions of each respondent using a self-reported questionnaire, and thus it potentially induces effects of common method bias that might attenuate the theoretical significance of the findings (Podsakoff et al. 2003). However, the results of meta-analysis by Christian et al. (2009) suggested that a “common methods bias may not be a major concern in safety domain.” In addition, this study followed Podsakoff et al. (2003)’s ‘a single unmeasured latent method’ approach to examine whether the bias would account for the relationships among the variables. Specifically, an unmeasured latent method factor in the CFA model was added and allowed all variables to load on their theoretical construct as well as the method factor. The factor loadings and correlations among the factors remain virtually unchanged after introducing the method factor, which also suggests that common method bias did not significantly inflate the results.

3.6 CONCLUSIONS

This chapter incorporates different sources of social norms (e.g., perceived management norms and workgroup norms) and personal attitudes and adopts social identity theory to build and test a theoretical model regarding construction workers’ safety behavior. The results of hypothesis testing suggest that: (1) perceived workgroup norms partially mediate the relationship between perceived management norms and safety behavior, (2) workers’ social identification with their project positively moderates relationship between perceived management norms and safety behavior and negatively moderates relationship between perceived workgroup norms and safety behavior. These findings deepen and extend prior research on construction safety as well as social identity by clarifying the mechanism that underlies the link between social influence and safety behavior. Also, findings from this study pave new directions for safety management in construction. As mentioned before, behavioral changes by social norms are a process of genuine internalization, and thus it would be more durable and cost effective. Therefore, socio-psychological approaches to promote positive management norms and workgroup norms would be an effective means to complement limitations of formal controls in construction safety management. Also, managerial actions to strengthen workers' social identification with their project will help to intensify positive social influence and diminish negative social influence on workers' safety behavior and ultimately improve workers' safety behavior.

CHAPTER 4

THE EFFECTS OF CULTURAL BACKGROUNDS AND ORGANIZATIONAL STRUCTURES ON SOCIAL INFLUENCE PROCESS[4]

4.1 INTRODUCTION

The previous chapters investigated how different social norms (e.g., perceived management norms and perceived workgroup norms) and social identities (e.g., project identity and workgroup identity) are related to construction workers' safety behavior. The results demonstrated significant influence of perceived management norm, perceived workgroup norm, and personal attitudes on workers' safety behavior. Also, the relationship between perceived management norms and safety behavior is partially mediated by the perceived workgroup norms. Furthermore, the relationship between the perceived management norms and safety behaviors is positively moderated by workers' social identification with their project and the relationship between the perceived workgroup norms and safety behavior is negatively moderated by project identity. The analyses included collective self-concept, which refers to the extent to which individuals define themselves in terms of group memberships (Johnson et al. 2006), and job experience as control variables.

However, it is still unclear whether the findings are stable across different cultural backgrounds and organizational structures. Previous cross-cultural studies have demonstrated that cultural contexts affect social influence process (Casey et al. 2015). For example, since

[4] This chapter is adopted from Choi, B. and Lee, S. (2017) "Role of Social Norms and Social Identifications in Safety Behavior of Construction Workers. II: Group Analyses for the Effects of Cultural Backgrounds and Organizational Structures on Social Influence Process." *Journal of Construction Engineering and Management*, 143(5), 04016125

collectivistic cultures, defined as “the broad value tendencies of a culture in emphasizing the importance of the ‘we’ identity over the ‘I’ identity” (Ting-Toomey 1999), emphasize group goals above individual needs (Triandis et al. 1990; Bandura 2001), influence of the group on an individual’s behavior is stronger than it would in individualistic culture (Hui and Triandis 1986). In addition, as mentioned earlier, the characteristics of organizational structure (e.g., subcontracting) in construction make social influence more complicated in construction projects. Construction workers would not have the same company identity with managers from a general contractor in case of the subcontracting, this can hinder the development of coherent safety norms among the project participants (e.g., misalignment between perceived management norms and perceived workgroup norms). On the other hand, if a general contractor directly hires workers for their work instead of subcontracting, relationship between social norms (e.g., perceived management norms and perceived workgroup norms) and effects of social norms on workers’ safety behavior in that site could be different from those in typical construction sites where general contractors subcontract most of their work.

With this background, the U.S., Korea, and Saudi Arabia are selected for the group analyses in this chapter because they are both different from and similar to each other in terms of cultural backgrounds and organizational structures. While the U.S. has been seen as individualistic culture, Korea and Saudi Arabia have been considered as collectivistic cultures (Hofstede Centre 2016). On the other hand, a large portion of contract work is subcontracted in the U.S. and Korea but general contractors for local construction project in Saudi Arabia have more chances to engage in direct hiring of workers due to a shortage of workforce, which provides more opportunities that workers can directly work with a general contractor. Group analyses of the three countries are expected to deepen and broaden our understanding of social influence on construction workers’ safety behavior by comparing patterns of social influence on construction workers’ safety behavior in different cultural backgrounds and organizational structures.

4.2 CULTURES AND ORGANIZATIONAL STRUCTURES IN THE U.S., KOREA, AND SAUDI ARABIA

Culture has been defined as "the collective programming of the mind which distinguishes the members of one group or category of people from another" (Hofstede 2001). Such collective programing is formed by shared beliefs and values that assume "how things ought to be or how one should behave" (Thomas et al. 2003) and thus guide an individual's behavior in social settings. Also, a number of studies have demonstrated the influence of cultural differences on safety contexts (Helmreich and Merritt 1998; Burke et al. 2008; Mearns and Yule 2009; Casey et al. 2015). Researchers in cross-cultural studies have identified a number of dimensions to distinguish different cultures. Among these dimensions, the one that has received most attention to explain social behavior is individualism-collectivism dimension (Triandis 1985). Individualism refers to "the tendency to view one's self as independent of others and to be more concerned about consequences of behavior for one's personal goals" (Thomas et al. 2003). Collectivism refers to "to view the self as interdependent with selected others, be concerned about consequences of behavior for the goals of the in-group, and be more willing to sacrifice personal interests for group welfare" (Thomas et al. 2003). Therefore, individuals' behaviors in the collectivistic cultures are more likely to be regulated by ingroup norms than individualistic cultures (Triandis et al. 1990). To distinguish the U.S., Korea, and Saudi Arabia in individualism–collectivism dimension, this study uses Hofstede's score as a measure of individualism and collectivism. Although there have been ongoing debates (e.g., McSweeney 2002; Hofstede 2002; Hofstede 2010) regarding the validity of Hofstede's score, it was deemed appropriate for this study given that it is one of the most widely applied cross-cultural research models in organizational behavior studies (Minkov and Hofstede 2011). According to the Hofstede Centre (2016), the U.S. culture is high in individualism (i.e., Hofstede score: 91) and Korea and Saudi Arabia are low in individualism (i.e., Hofstede score: 18 (Korea) and 25 (Saudi Arabia)). In other words, the U.S. can be categorized as an individualistic culture and Korea and Saudi Arabia are categorized as collectivistic cultures. In addition, the notion about individualism in western culture and collectivism in eastern culture has been supported by a number of other previous studies (Dion and Dion 1993; Triandis et al. 1988; Kashima et al. 1995). Therefore, it does not seem unreasonable to anticipate that people in the U.S. place a strong normative emphasis on independence of the self, whereas people in Korea and Saudi Arabia put much greater emphasis on interdependence of the self within the group. In this regard, comparing the U.S with Korea and Saudi Arabia helps us to explore the impacts of the cultural differences on social influence processes in construction projects.

As mentioned earlier, different company identities between managers and workers in the same project make social influence in construction projects complicated. However, this may be true for some countries while not in other countries. For example, while general contractors in the U.S. and Korea subcontract a large portion of contract work, general contractors for local construction projects in Saudi Arabia have more chances to engage in direct hiring of workers due to a shortage of workforce, even if general contractors in large-scale international projects (e.g., oil refinery construction project) subcontract some portion of their work. For example, Al-Harbi et al. (1994) showed that a majority of general contractors in Saudi Arabia subcontracts less than 25% of their work." In addition, instead of subcontracting the work, general contractors for local construction project in Saudi Arabia oftentimes rent trade workers from manpower suppliers when they do not have enough workers for their work. Renting workers from the supplier is more similar to direct hiring than subcontracting in terms of organizational structure because of the absence of supervisors from subcontractors. Since there is no supervisor from subcontractors in the site, workers are directly managed by and work with managers from a general contractor in the site. The authors selected construction projects where workers are directly working with a general contractor to investigate the impact of that organization structure on safety behavior. In the same vein, all participants in this study in Saudi Arabian construction projects are directly hired by the general contractors.

4.3 METHODS AND PARTICIPANTS

This study used the same data set from the previous chapter for the group analyses. For data collection, eight construction sites in the U.S. (two sites), Korea (two sites), and Saudi Arabia (four sites) were approached. Construction sites in the U.S. were a large sized research facility retrofit project and a waste water treatment plant renovation project. A large sized research facility building construction project and a university dormitory construction project were approached in Korea. Construction projects in Saudi Arabia were an office building, hospital, bridge, and tunnel construction project. The survey was conducted between June 2015 and September 2015.The questionnaires and survey procedures were reviewed and approved by Institutional Review Board (IRB) of the University of Michigan. The questionnaires were filled out in the conference room of each site at prearranged time, supervised by members of research team. One week prior to the survey, a safety manager of general contractor and research team members advertised the purpose and process of the survey to the foremen in a weekly meeting, and the foremen advertised the survey to their crew members. The workers at the sites voluntarily participated in the survey. Before starting the survey, members of research team provided a brief explanation of the purpose and procedure of the study. Questionnaires were completed anonymously, and completed questionnaires were collected immediately by administrators to guarantee the confidentiality of the response. The survey took approximately 20-25 minutes in total to complete.

75 workers in the U.S., 107 workers in Korea, and 102 workers in Saudi Arabia participated in this study. Workers in the Saudi Arabian sites are migrant workers from the Philippines, India, and Nepal. The authors decided not to divide them into three different groups because they do not have much difference in terms of cultural backgrounds as well as organizational structure. The Hofstede's score for the three countries are relatively low, and thus all the three countries can be categorized into collectivistic culture. Also, other previous studies categorized South Asia as collectivistic culture (Klassen 2004; Lalonde et al. 2004). In terms of organizational structure, the three countries are the same because all workers in the Saudi Arabia site are engaged in direct hiring system. The average age of the participants in the U.S. is 39.43 years (Standard Deviation (SD) = 10.81), Korea is 48.87 years (SD = 9.77), and Saudi Arabia is 33.41 years (SD = 8.80). Specifically, more than 70% of participants in Korea are older than 40 years but more than 70% of participants in Saudi Arabia are younger than 40 years. The average years of work experience of the U.S. participants is 15.94 years (SD = 9.79), Korea is 13.16 years (SD = 8.52), and Saudi Arabia is 6.82 years (SD = 4.73). More than 70% of participants in the U.S. have more than 10 year work experience but more than 70% of participants in Saudi Arabia have less than 10 year work experience. The average time spent in the current project of the U.S. participants is 7.9 months (SD = 6.35), Korea is 4.26 months (SD = 3.40), and Saudi Arabia is 8.79 months (SD = 5.45). More than 80% of participants in all the three countries spent less than 1 year in the current project. It reflects the transient nature of construction workforce. Detailed distributions of participants' demographics are presented in Table 1. All participants in the U.S. and Korea are hired by subcontractors while all participants in Saudi Arabia are hired by general contractors.

Table 4.1 Demographics of Participants in the Three Countries

Demographics	U.S	Korea	Saudi Arabia
Age			
≤ 30 y	26.7 %	3.8 %	48.2 %
31 – 40 y	24.0 %	14.2 %	30.1 %
41 – 50 y	26.7 %	34.9 %	15.7 %
≥ 50 y	22.7 %	47.2 %	6.0%
Years of work experience			
≤ 5 y	19.7 %	21.2 %	47.7 %
6 – 10 y	15.5 %	28.9 %	30.2 %
11 – 15 y	21.1 %	19.2 %	16.3 %
≥ 16 y	43.7 %	30.8 %	5.8%
Time spent in the current project			
≤ 6 m	51.4 %	77.0 %	38.5 %
7 – 12 y	29.7 %	21.0 %	46.2 %
≥ 1 y	18.9 %	2.0 %	15.4 %

4.4 RESULTS AND DISCUSSIONS

The data are analyzed using SPSS 20.0 software and Hayes (2013)'s PROCESS macro. First of all, reliabilities of the measuring scales (i.e., perceived management norm, perceived workgroup norm, project identity, workgroup identity, collective self-concept, attitude, and safety behavior) are tested using a Cronbach's Alpha test. Then, structures of construction workers' social identity (i.e., salience of project identity and workgroup identity) in the three countries are analyzed. Next, current states of construction safety in the three countries are analyzed by comparing strictness of perceived management norm, perceived workgroup norm, and workers' own opinion. Finally, the results of the multiple regression analysis predicting safety behavior in the three countries are compared.

The descriptive statistics and reliability scores (i.e., Cronbach Alpha) of the variables in the three countries are presented in Table 2. As shown in Table 2, the reliability scores for all measuring scales in the three countries exceed the acceptable level of .60 (Hair et al. 2006).

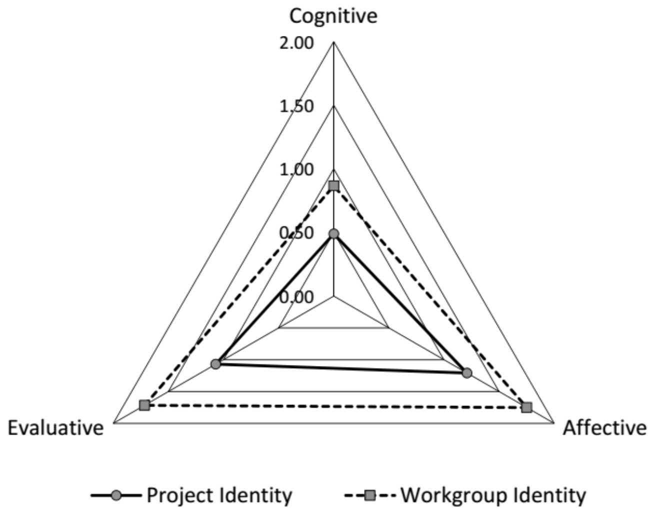
Table 4.2 Descriptive statistics and reliability in the three countries

Variables	U.S.			Korea			Saudi Arabia		
	Mean	SD	Alpha	Mean	SD	Alpha	Mean	SD	Alpha
Perceived management norm	2.16	.76	.72	1.35	1.22	.84	1.34	1.44	.76
Perceived workgroup norm	1.33	.92	.66	.76	1.49	.81	1.37	1.40	.60
Project identity	.92	.92	.76	.83	1.08	.90	1.50	1.08	.79
Workgroup identity	1.44	.79	.76	1.21	1.02	.87	1.56	1.11	.85
Collective self-concept	2.12	.84	.91	1.59	.97	.87	1.92	1.12	.70
Attitude	1.15	1.06	.83	1.55	.96	.84	1.55	1.18	.72
Safety behavior	1.65	1.08	.77	1.37	1.19	.87	1.61	1.26	.69

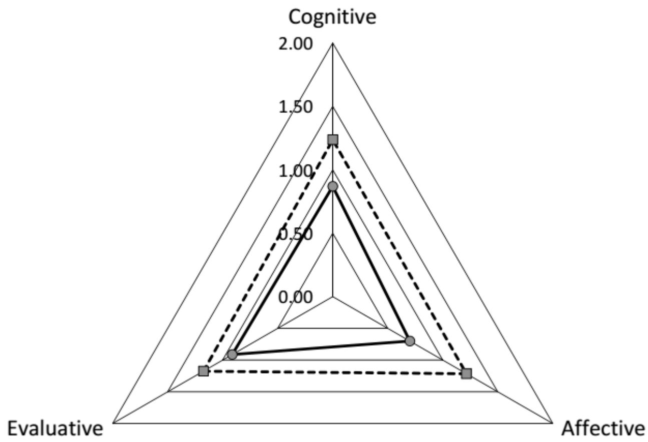
N = 75 (U.S.), 107 (Korea), and 102 (Saudi Arabia)

4.4.1 Project Identity and Workgroup Identity

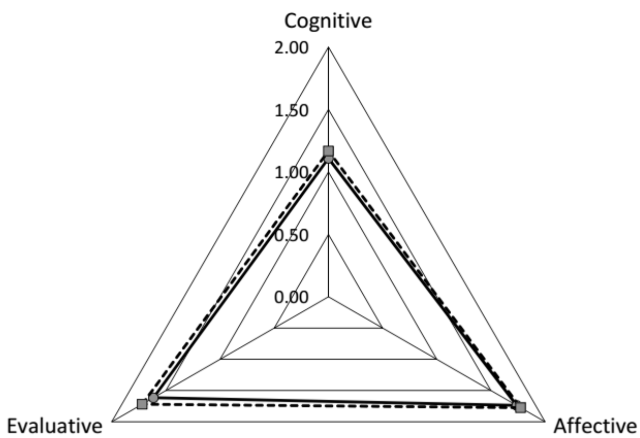
Figure 4.1 shows a graphical representation of workers' social identification with their project and workgroup in the three countries. In Figure 4.1, each vertex of a triangle represents each dimension of social identity (i.e., cognitive, affective, and evaluative dimension), and thus a larger triangle refers to a more salient social identity. Figure 4.1 demonstrates that workers in the Saudi Arabian sites have strong project identity compared with the U.S. and Korea. There are measurable differences between project identity and workgroup identity in the U.S. and Korea. In these two countries, workgroup identity is more salient than project identity in all dimensions. However, differences between project identity and workgroup identity are insignificant in Saudi Arabia.



(a) United States



(b) Korea



(c) Saudi Arabia

Figure 4.1 Project Identity and Workgroup Identity in the Three Countries

To statistically test the differences between project identity and workgroup identity in the three countries, paired t-tests are conducted for each dimension of project identity and workgroup identity. As shown in Table 4.3, the results of the paired t-tests confirm the results of descriptive analyses. In the U.S., there are significant differences between project identity and workgroup identity in all three dimensions. Also, the mean differences between project identity and workgroup identity in Korea are significant in all dimensions. However, there are not significant differences between project identity and workgroup identity in all dimensions in Saudi Arabia.

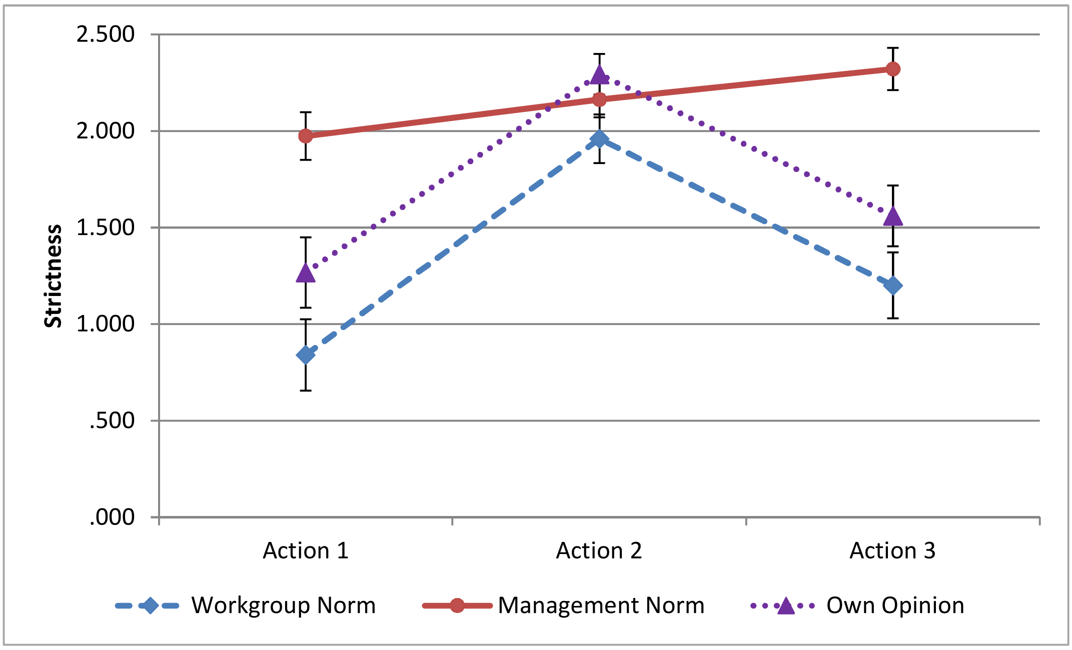
Table 4.3 Paired t-tests between Project Identity and Workgroup Identity in the Three Countries

Country	Dimension	Project Identity		Workgroup Identity		n	Mean difference	t	*p*
		Mean	SD	Mean	SD				
U.S.	Cognitive	.49	1.02	.87	1.06	75	-.38	-3.24	.002
	Affective	1.21	1.24	1.75	.99	75	-.54	-3.64	.001
	Evaluative	1.07	1.08	1.72	.82	75	-.64	-6.45	.000
Korea	Cognitive	.87	1.01	1.24	1.03	107	-.37	-4.57	.000
	Affective	.70	1.27	1.22	1.14	107	-.51	-5.84	.000
	Evaluative	.91	1.25	1.17	1.25	107	-.26	-2.58	.011
Saudi Arabia	Cognitive	1.11	1.33	1.17	1.39	101	-.06	-.45	.657
	Affective	1.74	1.29	1.77	1.22	101	-.03	-.28	.777
	Evaluative	1.62	1.26	1.72	1.19	102	-.10	-.82	.415

A possible interpretation for this result is that the direct hire systems in the Saudi Arabian sites can contribute to this strong project identity. Since workers in the Saudi Arabian sites are directly hired by a general contractor, they will belong to the same general contractor even if they move to other sites after completing their own task in the current project. The current project, therefore, would be perceived as a part or department of the general contractor for workers in the Saudi Arabian sites. Also, all workers and managers in the current project can share a company identity as their common background, and thus workers can easily find similarities among the project members. Since the salience of social identity is known to be determined by similarities within a group and differences between groups (Oakes et al. 1991), the direct hire systems in the Saudi Arabian sites might be attributable to the strong project identity. Also, workers from the manpower suppliers could easily find similarity with managers from a general contractor because there is no supervisor from subcontractor and manager from manpower supplier in the site. In other words, since workers in the site are directly managed by and work with mangers from a general contractor, they could perceive that they belong to the same organization (i.e., project) with managers from a general contractor. On the other hand, workers in the U.S. and Korea are hired by subcontractors and thus workers and managers from a general contractor do not share the company identity. Also, since a general contractor subcontract with a number of subcontractors in a construction project, there are a number of company identities in one construction project. In this organizational structure, workers' social identification with their project cannot be strong because similarity within the project members is low and difference among the project members is high.

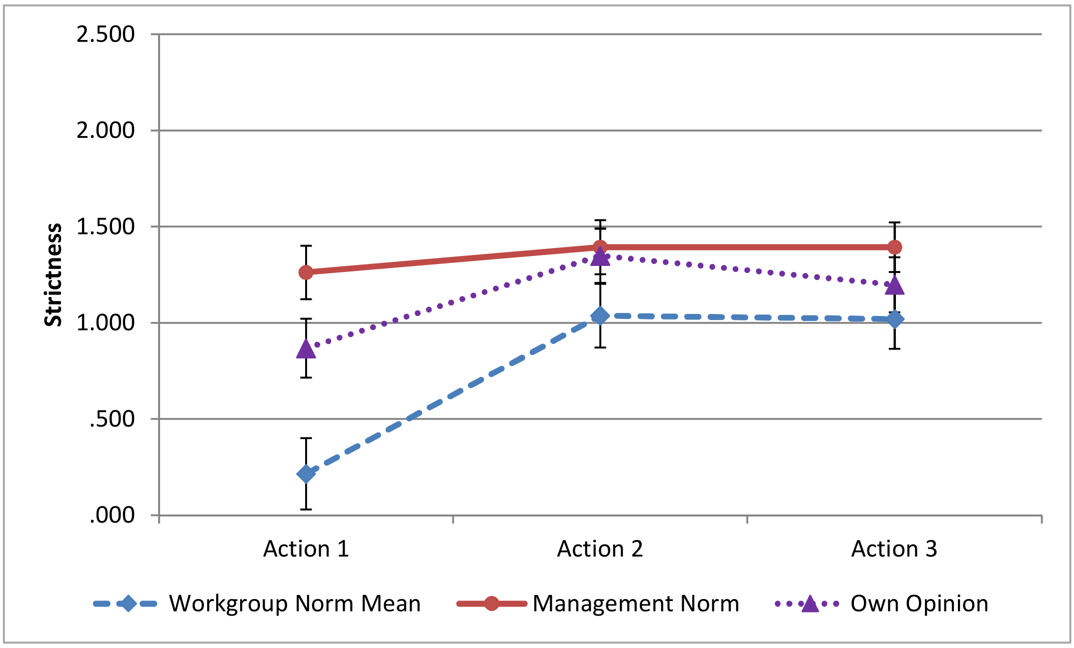
4.4.2 Perceived Management norm, Perceived Workgroup Norm, and Own Opinion

The current status of perceived management norm, perceived workgroup norm, and workers' own opinion in the three countries are represented in Figure 4.2. To visualize the misalignment among perceived management norms, perceived workgroup norms, and workers' own opinions, the means of the responses for the three variables in each situation are plotted. In Figure 4.2, X axis represents the three situations (i.e., stop working with no anchor point to connecting the snap hook, putting on uncomfortable safety glasses, and tying safety harness in no perceived danger of falling) that are used to measure perceived management norm, perceived workgroup norm, and workers' own opinion and Y axis refers to the strictness of the norms. As shown in Figure 4.2, the U.S. and Korea demonstrate similar patterns of misalignments between perceived management norms and perceived workgroup norms while Saudi Arabia shows a different pattern. In the U.S. and Korea, there are measurable misalignments between perceived management norms and perceived workgroup norms in all the three situations, but there are no significant differences between perceived management norms and perceived workgroup norms in Saudi Arabia. In other words, perceived management norms are stricter than perceived workgroup norms for all situations in the U.S. and Korea. Another noticeable point is that workers' own opinions stand between perceived management norms and perceived workgroup norms for all situations in the U.S. and Korea except for the second situation in the U.S. (i.e., wearing uncomfortable safety glasses). This result shows conflicts between perceived management norms and perceived workgroup norms in shaping workers' own opinions in uncertain situations. This implies that in ambiguous situations related to safety, workers would not fully follow the perceived management norms even if they already perceived strict norms from their managers, because the level of their coworkers' safety behaviors is below the perceived management norms.



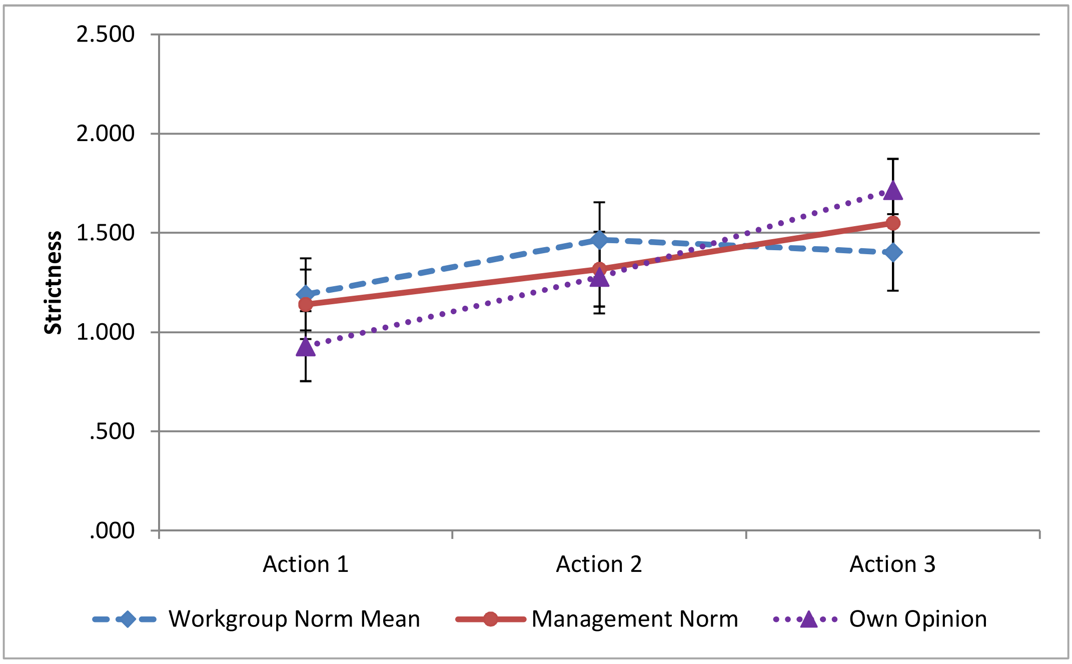
Note: Mean with standard error

(a) United States



Note: Mean with standard error

(b) Korea



Note: Mean with standard error (c) Saudi Arabia

Figure 4.2 Management Norm, Workgroup Norm, and Workers' Own Opinion in the Three Countries

To demonstrate statistical significance of these patterns, paired t-tests between m perceived management norms and perceived workgroup norms are conducted for all situations in the three countries. The results of the paired t-tests reaffirm results of the descriptive analyses. There are significant mean differences between perceived management norms (action 1: Mean (M) = 1.97, Standard Deviation (SD) = 1.07, action 2: M = 2.17, SD = .79, and action 3: M = 2.32, SD = .95) and perceived workgroup norms (action 1: M = .83, SD = 1.60, action 2: M = 1.97, SD = 1.09, and action 3: M = 1.28, SD = 1.48) in the U.S. (action 1: t (74) = 15.76, p = .000, action 2: t (74) = 4.30, p = .000, and action 3: t (74) = 14.42, p = .000). Also, significant mean differences between perceived management norms (action 1: M = 1.26, SD = 1.44, action 2: M = 1.39, SD = 1.45, and action 3: M = 1.39, SD = 1.33) and perceived workgroup norms (action 1: M = .22, SD = 1.92, action 2: M = 1.04, SD = 1.71, and action 3: M = 1.02, SD = 1.60) are found for all situations in Korea (action 1: t (106) = 6.13, p = .000, action 2: t (106) = 2.43, p = .017, and action 3: t (106) = 2.66, p = .005). However, the mean differences between perceived management norms (action 1: M = 1.14, SD = 1.75, action 2: M = 1.32, SD = 1.89, and action 3: M = 1.55, SD = 1.60) and perceived workgroup norms (action 1: M = 1.19, SD = 1.81, action 2: M = 1.47, SD = 1.90, and action 3: M = 1.40, SD = 1.95) are not significant in Saudi Arabia (action 1: t (99) = -.28, p = .783, action 2: t (100) = -.86, p = .390, and action 3: t (101) = .84, p = .402).

Non-significant mean differences between perceived management norms and perceived workgroup norms in Saudi Arabia can be interpreted in two different ways. The first interpretation is that a strong project identity in Saudi Arabia contributes to the coherence between perceived management norms and perceived workgroup norms. In other words, perceived workgroup norms in Saudi Arabia could be strict enough that they approximate the management norms due to workers' strong project identity. Workers in the Saudi Arabian sites perceived their coworkers and managers as the members of the same group (i.e., project), and thus they may not differentiate management norms and workgroup norms. The second interpretation is that perceived management norms in the Saudi Arabian sites may not be strict enough to differ from perceived workgroup norms. It might be possible that managers in the same project fail to achieve consensus on the strictness of safety norms. Some managers may have very strict safety norms but others can have little lenient safety norms. In this case, some workers, who are influenced by very strict manager, have strict perceived management norms but others may not have such strict perceived management norms.

To further investigate and confirm these interpretations, within-group agreements on the perceived management norms in all the eight sites were compared. The within-group agreement refers to the degree to which ratings from the same group members are interchangeable (Bliese 2000), and thus it reflects the within-group homogeneity. The within-group agreements are assessed by using rwg statistic (James et al. 1984) which is widely used in safety climate studies (Zohar 2000; Zohar and Luria 2005). Table 4 represents within-group agreement and mean of the perceived management norm in the eight sites. As shown in Table 4, within-group assignment in all the two sites in the U.S. exceed the .70 threshold recommended by Bliese (2000). On the other hand, within-group agreements of three of the four sites in Saudi Arabia are below the threshold, and one of the two sites in Korea fails to exceed the threshold. It is important to note that all sites which exceed the threshold in the three countries tend to have stricter perceived management norm than other sites. It implies that inconsistent perceived management norms among the workers in the same project might be a reason for lenient management norms in the project. The comparisons in within-group agreement among the eight sites, therefore, support the second interpretation of non-significant differences between perceived workgroup norms and perceived management norms in Saudi Arabia (i.e., not strict enough perceived management norms to differ from the perceived workgroup norms).

Table 4.4 Within Group Agreement on Perceived Management Norm in the Eight Projects

Country	Project	Perceived management norm	
		r_{wg}	Mean
Unite States	A	0.866	2.222
	B	0.852	2.130
Korea	C	0.524	0.765
	D	0.792	1.757
Saudi Arabia	E	0.787	1.710
	F	0.334	1.063
	G	0.601	1.526
	H	0.351	1.472

N = 21 (Site A), 54 (Site B), 44(Site C), 63 (Site D), 23 (Site E), 48 (Site F), 19 (Site G), 12 (Site H)

4.4.3 Results of Regression Analyses

As the next step, it was attempted to fit the multiple regression model predicting safety behavior to data separately collected from the three countries. Table 4.5 shows the results of the multiple regression analysis in the U.S. As shown in Table 4.5, project identity (V) positively interacts with perceived management norm (X) (β_{27} = .46, t = 2.87, p = .006) and negatively interacts with perceived workgroup norm (M) (β_{28} = -.36, t = -2.35, p = .022) to predict safety behavior. The result clearly shows the moderating effect of project identity on the social influence process. In other words, the relationship between the perceived management norms and safety behavior is stronger and the relationship between the perceived workgroup norms and safety behavior is weaker for workers who show higher project identity. Also, the result shows that personal attitude (A) significantly predict safety behavior (β_{25} = .46, t = 2.87, p = .006). The value of R-square is .641 which implies that the multiple regression model explains 64.1% of variance in safety behavior. After the regression analysis, the white test was performed to test the homoscedasticity assumption of the regression analysis and no heteroscedasticity was found (p = .178). Also, variance inflation factors (VIFs) were computed to examine the multicollinearity issue in the regression. The value of VIF for all variables range from 1.09 to 5.86, which are far below the threshold of 10.0 (Nunnally and Bernstein 1994), thus suggesting that multicollinearity was not a major issue in this study.

Table 4.5 Result of Multiple Regression Analysis of the U.S. Sample

Prediction of safety behavior (Y)

$$= \beta_{20} + \beta_{21}X + \beta_{22}M + \beta_{23}V + \beta_{24}Q + \beta_{25}A + \beta_{26}C + \beta_{27}X(V) + \beta_{28}M(V) + \beta_{29}X(Q) + \beta_{30}M(Q) + \varepsilon_2$$

Variable	b	β	S.E	R^2	F
Management Norm (X) - β_{21}	.383	.268	.215	.641	11.45
Workgroup Norm (M) - β_{22}	.233	.204	.175		
Project Identity (V) - β_{23}	.102	.087	.107		
Collective Self (Q) - β_{24}	.337**	.262**	.126		
Attitude (A) - β_{25}	.224*	.220*	.097		
Experience (C) - β_{26}	-.013	-.115	.009		
Management Norm x Project Identity (X(V)) - β_{27}	.726**	.461**	.253		
Workgroup Norm x Project Identity (M(V)) - β_{28}	-.506*	-.385*	.215		
Management Norm x Collective Self (X(Q)) - β_{29}	.050	.030	.286		
Workgroup Norm x Collective Self (M(Q)) - β_{30}	-.176	-.111	.292		

Note: N = 75, *p < .05, **p < .01

Table 4.6 shows the results of the multiple regression analysis in Korea. As shown in Table 4.6, interaction between project identity (V) and perceived management norm (X) (β_{27} = .39, t = 2.33, p = .022) and between project identity (X) and perceived workgroup identity (M) (β_{28} = -.54, t = -3.35, p = .001) significantly predict safety behavior (Y). The result is consistent with the U.S. However, unlike the U.S., regression coefficient of attitude (A) is not significant in Korea (β_{25} = .14, t = 1.75, p = .084). On the other hand, regression coefficients of perceived management norm (β_{21} = .42, t = 2.39, p = .019) and perceived workgroup norm (β_{22} = .38, t = 4.15, p = .000) are significant in Korea. It implies that perceived management norm and perceived workgroup norm are still significantly associated with safety behavior after controlling the interaction effect related with the norms. The result of white test suggests that there is no heteroscedasticity issue (p = .162). In addition, the values of VIFs for all variables range from 1.18 to 5.81 which are far below the threshold of 10.0 (Nunnally and Bernstein 1994).

Table 4.6 Result of Multiple Regression Analysis of Korea Sample

Prediction of safety behavior (Y)
$= \beta_{20} + \beta_{21}X + \beta_{22}M + \beta_{23}V + \beta_{24}Q + \beta_{25}A + \beta_{26}C + \beta_{27}X(V) + \beta_{28}M(V) + \beta_{29}X(Q) + \beta_{30}M(Q) + \varepsilon_2$

Variable	b	β	S.E	R^2	F
Management Norm (X) - β_{21}	.234*	.242*	.098		
Workgroup Norm (M) - β_{22}	.301**	.379**	.073		
Project Identity (V) - β_{23}	.126	.115	.108		
Collective Self (Q) - β_{24}	.086	.070	.115		
Attitude (A) - β_{25}	.174	.141	.100	.605	14.71
Experience (C) - β_{26}	-.005	-.033	.010		
Management Norm x Project Identity (X(V)) - β_{27}	.309*	.389*	.132		
Workgroup Norm x Project Identity (M(V)) - β_{28}	-.381**	-.540**	.114		
Management Norm x Collective Self (X(Q)) - β_{29}	-.016	-.018	.107		
Workgroup Norm x Collective Self (M(Q)) - β_{30}	.167	.193	.103		

Note: N = 107, *p < .05, **p < .01

Different cultural contexts in the U.S. and Korea can offer a possible interpretation of different independent significant predictors in the regression analysis in the two countries. Attitude is a significant independent predictor of safety behavior in the U.S., which has been considered as an individualistic culture, but social norms (e.g., perceived management norms and perceived workgroup norms) are significant independent predictors of safety behavior in Korea, which has been seen as a collectivistic culture. Attitude refers to "the degree to which a person has a favorable or unfavorable evaluation of the behavior in question" (Ajzen and Madden 1986). In this regard, attitude reflects "the way a person expresses their own beliefs and values" (Pavord et al. 2014). A person in the individualistic culture is more concern about "consequences of one's behavior on one's own needs, interests, and goals" (Leung 1988). Therefore, individualistic culture in the U.S. may contribute to a significant association between attitudes and safety behavior. On the other hand, a person in collectivism culture is more concern about "consequences of one's behavior on ingroup members" (Leung 1988). Therefore, collectivistic culture in Korea may lead to significant associations between perceived management norms and safety behavior and between perceived workgroup norms and safety behavior after controlling the interaction effects.

Table 4.7 shows the results of the multiple regression analysis in Saudi Arabia. In Saudi Arabia, the interaction term of perceived management norm (X) and project identity (V) (β_{27} = .12, t =.52, p = .607) as well as perceived workgroup norm (M) and project identity (V) (β_{28} = -.20, t =

-1.55, p = .125) are not significant predictors of safety behavior. Therefore, project identity and collective self-concept and their interaction terms are excluded in the regression analysis. As shown in Table 4.7, perceived management norm (X) is the only variable that emerges as an independent significant predictor of safety behavior in the analysis (β_{21} = .44, t = 2.53, p = .013). However, perceived workgroup norm (M) (β_{22} = -.02, t = -.11, p = .909) and attitude (A) (β_{25} = .08, t =.75, p = .452) do not show a significant association with safety behavior. The value of R-square is .248 which implies that the multiple regression model explains 24.8% of variance in safety behavior. The result of white test finds heteroscedasticity issue in this regression analysis. To address the heteroscedasticity issue, Huber-White standard errors which can relax the assumption of homoscedasticity are used in this analysis. On the other hand, the values of VIFs for all variables range from 1.07 to 2.09 which are far below the threshold of 10.0 (Nunnally and Bernstein 1994).

Table 4.7 Result of Multiple Regression Analysis of Saudi Arabia Sample

Prediction of safety behavior (Y)
$= \beta_{20} + \beta_{21}X + \beta_{22}M + \beta_{23}A + \beta_{24}C + \varepsilon_2$

Variable	b	β	S.E	R^2	F
Management Norm (X) - β_{21}	.388**	.444**	.110		
Workgroup Norm (M) - β_{22}	-.016	-.018	.114	.248	7.98
Attitude (A) - β_{25}	.082	.077	.098		
Experience (C) - β_{26}	-.039	-.135	.026		

Note: N = 102, *p < .05, **p < .01

Although workers in Saudi Arabian site show a strong project identity compared with the U.S. and Korea, interaction between project identity and perceived management norm and between project identity and perceived workgroup norm are not significant in Saudi Arabia. On the other hand, project identity contributes to a stronger association between perceived management norms and safety behavior and a diminished association between perceived workgroup norms and safety behavior in the U.S. and Korea. In other words, workers who have a strong project identity in the U.S. and Korea are more likely to be influenced by strict perceived management norms, even if their coworkers do not follow the perceived management norms. However, as mentioned earlier, there is no significant difference in strictness between perceived management norms and perceived workgroup norms in Saudi Arabia. It implies that there is no conflict between perceived management norms and perceived workgroup norms, and thus the moderating role of project identity in social influence process could be limited in Saudi Arabia.

The results of this chapter have important practical implications for construction safety management in the three countries. First of all, the results suggest that promoting desirable social norms (e.g., perceived management norms and perceived workgroup norms) regarding safety behavior can contribute to improving construction safety. In the U.S. and Korea, strengthening workers' willingness to follow strict perceived management norms and to disregard lenient perceived workgroup norms would be effective to ameliorate workers' safety behavior, because perceived management norms are significantly stricter than perceived workgroup norms. The results of multiple regression analyses in the two countries suggest that enhancing workers' project identity could strengthen the positive impact of perceived management norms and to diminish the negative impacts of perceived workgroup norms, which may ultimately improve workers' safety behavior. Previous studies in social identity theory suggested various ways such as symbolic management, communication among the group members, etc. to enhance individual's social identification with organizations. These strategies could be considered to strengthen workers' social identification with their project in the U.S. and Korea. For example, providing uniquely designed personal protective equipment (e.g., safety harness, safety glasses, hard hat, etc.) which emphasizes project membership sayings like "We are constructing the largest library in Ann Arbor" can evoke commonality among the project members and ultimately foster workers' social identification with their project. In addition, encouraging positive attitudes toward safety behavior would be helpful to improve workers' safety behavior in the U.S. because its individualistic culture contributes to the significant association between personal attitudes and safety behavior. In this regard, safety trainings which show the benefits of safety rules and loss of unsafe behaviors could be an effective way to promote workers' positive attitude and ultimately to improve their safety behavior.

On the other hand, in Saudi Arabia, promoting strict perceived management norms would be a priority, because perceived management norms are not strict enough to differ from workgroup norm, and project identity is already salient due to the direct hiring systems. Considering the association between within group agreement and strictness of perceived management norms, dissonance in strictness of perceived management norms in the same project would be an obstacle to promote strict management norm. Therefore, it is important to note that all managers in the same project should achieve consensus on the strictness of safety norms and provide a consistent feedback on workers' unsafe behaviors. For example, safety training sessions for other types of managers provided by a safety manager might be an effective approach to establish consistent management norms in the same project. In the session, safety managers can have an opportunity to share their safety standards with other types of managers, and thus the session can contribute to achieving consensus on the strictness of safety norms. In the session, safety managers can have an opportunity to share their safety standards with other types of managers, and thus the session can contribute to achieving consensus on the strictness of safety norms. It is expected that a salient project identity in Saudi Arabia will foster positive effects of perceived management norms on safety behavior after improving management norm. The differences among the three countries in this study suggest that although socio-psychological approaches have enough potential to improve construction safety, construction managers should pay attention to cultural and organizational context of the project.

4.5 CONCLUSIONS

This chapter examines and compares the role of perceived management norms, perceived workgroup norms, and project identity in construction workers' safety behavior in the U.S., Korea, and Saudi Arabia. From the results of the study, it is concluded that social norms (e.g., perceived management norms, and perceived workgroup norms) are significant predictors of safety behavior, but the three countries show different relationships among the variables in the regression analysis due to different cultural and organizational context. It was found that workers' social identification with their projects is an important mechanism that moderates the relationship between social norms (e.g., perceived management norms and perceived workgroup norms) and safety behavior in the U.S. and Korea. Also, the individualistic culture in the U.S. may lead to a direct effect of personal attitudes on safety behavior, and the collectivistic culture in Korea can bring about the direct effects of perceived management norms and perceived workgroup norms on safety behavior after controlling moderation effect of project identity. On the other hand, in Saudi Arabia, although workers already have a salient project identity due to the direct hiring system, interactions between project identity and social norms are not significant predictors of safety behavior because perceived management norms may not be strict enough to elicit behavioral changes in improving safety behavior.

The findings from this chapter lay a theoretical foundation for a new approach to safety management in international construction projects. International construction projects are challenging due to the fact that they involve the heterogeneity of cultural and organizational context (Gunhan and Arditi 2005). Particularly, the safety issues that can be caused by these heterogeneities create a significant concern to the organizations who execute the international construction projects (Mahalingam and Levitt 2007; Mearns and Yule 2009). In this regard, the results of this chapter can help the organizations understand what and how can improve workers' safety behaviors in a social influence perspective. Further, beyond the socio-psychological aspect of safety behavior, construction managers in the international projects should pay attention to cultural and organizational context of the project. For example, construction managers in the project using direct hiring systems should put more efforts to promote positive social norms rather than attempting to strengthen workers' project identity, because the organizational structure of the project make the workers strongly identify with their project. Therefore, considerations of cultural and organization contexts in international construction projects would be essential to strengthen positive social influence on workers' safety behavior.

Although findings from this study extend understanding of effects of cultural backgrounds and organizational structures on social influence process, some limitations should be acknowledged. First, this study did not take into account differences in government policies between the three countries. Since safety policy, procedure, and practice in construction sites should meet government's requirements, government policies would be a critical factor affecting managers' recognition of the importance of safety. As such, government policy can interact with the effects of management norms on workers' safety behaviors. Therefore, additional research efforts are required to investigate the effects of government policies on social influence process. Also, it is disputable that the results from each country are generalizable because of the modest size of samples in each country, although the surveys are conducted in multiple sites in each country. Specifically, the organizational structure of construction projects in Saudi Arabia could be affected by the characteristics of general contractors. While local general contractors tend to directly hire their workers and work with them for a long, international companies may prefer to subcontract a large portion of their work. In addition, the results of this study are based on a cross-sectional design, which prevents drawing causal relationship among the variables. Therefore, longitudinal studies with a larger size of samples could be used to gain a greater validity and greater generalizability of the results in future research.

CHAPTER 5

AN EMPIRICALLY BASED AGENT-BASED MODEL OF THE SOCIO-COGNITIVE PROCESS OF CONSTRUCTION WORKERS' SAFETY BEHAVIOR[5]

5.1 INTRODUCTION

This chapter introduces a study to create a formal behavioral model for construction workers' safety behaviors that integrates safety decision-making process and social influence to explore group-level safety behaviors using agent-based modeling (ABM) and simulations. While findings from the previous chapters have provided unique insights into the role of different social norms and social identities in shaping workers' safety behaviors, it is hard to uncover how workers' safety decision-making process interacts with social influence to affect their safety behaviors. Also, it is not clear how different site risk conditions affect the socio-cognitive process and safety behaviors. Finally, cross-sectional studies in the previous chapters are limited to investigate how individuals in an organization will react and which group-level phenomena will emerge when management's policies/interventions are implemented.

With this background, the main objective of this chapter is to investigate: (1) how construction workers' cognitive processes interact with social influence to produce their safety behaviors; and (2) how workers' socio-cognitive process of safety behavior interacts with different safety management interventions and different site risk conditions. To achieve the objectives, ABM and experimental analyses with simulation are utilized. ABM allow us to uncover the

[5] This chapter is adopted from Choi, B. and Lee, S. (2018) "An Empirically Based Agent-Based Model of the Sociocognitive Process of Construction Workers' Safety Behavior." *Journal of Construction Engineering and Management*, 144(2), 04017102.

underlying mechanism of social psychological phenomena emerging from individuals' interactions in an organization (Epstein 1999; Macy and Willer 2002). In the model, heterogeneous agents make their own decision and interact with the environments including other agents over time based on simple rules of behavior (Bonabeau 2002; Janssen and Ostrom 2006; Law 2013). The modeler can observe the group level phenomena emerging from the interaction in the system by running the simulation model (Gilbert 2008). In this regard, ABM bridges between "the micro level of assumption regarding individual agent behaviors, interagent interaction, and so forth and the macro level of the overall patterns that results in the agent population" (Smith and Conrey 2007). These attributes make ABM particularly well-suited for the purpose of this paper. This paper develops a model of workers' safety behavior that incorporates workers' cognitive process and their interaction with the environment (i.e., coworkers, managers, and site risk condition) based on theories and empirical findings from the literature. In addition, "thought experiments" (Macy and Willer 2002) are conducted to enhance understandings of workers' safety behavior and develop an idea of effective safety management strategies in different site risk conditions.

5.2 METHODS

In this section, the details of the model are described using the Overview, Design concept, Details (ODD) protocol (Grimm et al. 2006; Grimm et al. 2010). The ODD (Overview, Design concept, Detail) protocol is "a generic format and a standardized structure" to document individual-based and agent-based models (ABMs) (Grimm et al. 2010). The ODD protocol consists of three blocks (i.e., Overview, Design concept, and Detail) divided into seven elements (i.e., Purpose, Entities, state variables, and scales, Process overview and scheduling, Design concepts, Initialization, Input data, and Submodel), and describes how to explain each element in the protocol. The ODD protocol has been applied in diverse areas such as ecology, behavioral science, social science, epidemiology, and so on to promote the clarity, comprehensiveness, and reproducibility of the model (Anderson and Lee 2016). The following subsections describe the model using each element of the ODD protocol.

5.2.1 Purpose

The model detailed below has been developed to understand the role of construction workers' socio-cognitive process in safety behavior. Construction workers have many points of interaction with their environment, including interaction with coworkers, managers, and complex work conditions. Knowledge around safety behavior is currently limited to investigating the impact of the interaction between workers' cognitive processes and the environment. Previous empirical studies have been unable to uncover the mechanism behind the relationship between social influence and safety behavior. As such, the model that integrates workers' safety decision-making processes and their interaction with the environment (i.e., risk perception, workgroup norm perception, and management norm perception) has been developed in this paper. Additional purposes are to examine the effects of different safety management strategies (i.e., different strictness and frequency of management feedback and stimulation of workers' project identification) on safety behaviors in different site conditions (i.e., low, moderate, and high-risk site condition) in order to help construction practitioners develop effective safety management strategies to reduce workers' unsafe behaviors in their projects.

5.2.2 Entities, State Variables, and Scales

The agents in this model are the construction workers working on an artificial construction project. The attributes of each project are represented by following state variables; site risk, strictness of management feedback, and frequency of management feedback. The site risk represents the overall hazard level of the project that includes the likelihood of workers being exposed to an unsafe condition and the average risk level of the unsafe conditions on the site. Unsafe condition refers to a work condition that requires proactive safety actions along with the decision-making process to prevent accidents in this model. The risk level of the unsafe condition is related to the probability of accident occurrence, with a range of 0 to 1, and noted as 'actual risk' in the model. On the other hand, the strictness and frequency of management feedback represent safety management practices in the project. The strictness of management feedback refers to the risk acceptance level of the management, with a range of a 0 to 1. Operationally, the strictness of management feedback is defined as 1- risk acceptance level of the management. As such, a high value of the strictness implies that management does not tolerate moderate risk at the project. The frequency of management feedback indicates the likelihood that workers receive feedback from managers regarding their unsafe actions on the site.

Also, each worker has the following state variables; ID number, Workgroup ID number, risk attitude, risk acceptance, the salience project identity, and unsafe behavior. Risk attitude refers to an individual's tendency to take or avoid risk, with a range of 0 to 1 (risk adverse – risk seeking). The risk acceptance refers to an individual's tolerance to risk during their work, with a range of 0 to 1. The risk acceptance is an individual's internal standard to determine safety behavior in the model. A high value of risk acceptance implies that an individual accepts the high-risk work condition and do not perform a safe behavior to prevent an accident. The salience of the project identity represents an individual's degree of identification with the current project, and it is related to the willingness to follow management norm based on the results of Chapter 3. Lastly, the unsafe behavior is represented as a binary variable in the model (1 = unsafe action, 0 = safe action).

5.2.3 Process overview and Scheduling

The model proceeds in day time step and represents individual workers who perform safety behavior based on the interaction between their cognitive process and the environment (i.e., site condition, coworkers, and management). When the model initialized, it first creates a site condition and all workers presented in the simulated site and sets and stores their initial value of the state variables. After initializing the site condition and workers, the model begins to progress forward in time and simulate workers' safety behavior. During each time step, every worker has a chance to be exposed to the safe or unsafe condition and decide the safety behavior (i.e., safe/unsafe behavior). To make a decision, workers compare the perceived risk and their risk acceptance that is drawn from their risk attitude, and perception of workgroup norm and management norm. Workers' perception of workgroup norm and management norm are the result of their interaction with coworkers and management. Workers' safety behavior could result in an undesirable event (i.e., near miss or accident), or nothing happens, and the result will be the source of updating their memory. Specifically, how workers make a decision and update their memory is explained further detail in Section Submodels. After all the workers have had the opportunity to perform safety behavior, the model updates and each worker's state variables are collected that time step. Then, the group-level variables such as unsafe behavior ratio and incident rate are calculated and stored.

The simulation run terminates after 200 days of simulation time. Figure 5.1 shows a flowchart of the model's logic.

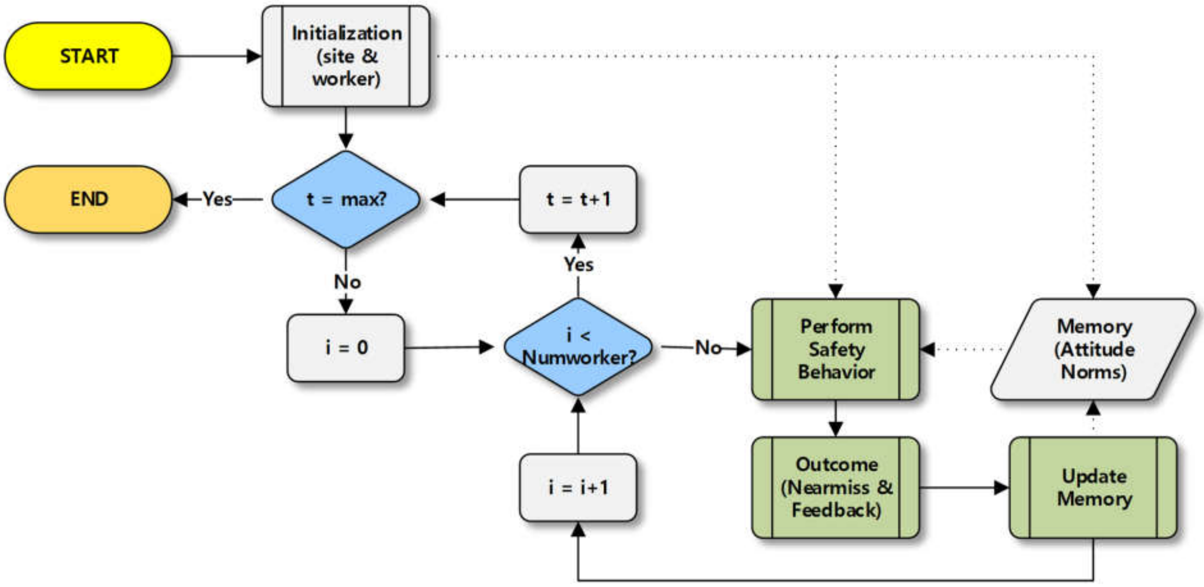


Figure 5.1 Model Process Flowchart

5.2.4 Design Concept

The *basic principle* of this model is based on an integration of theories and concepts in social science literature as well as empirical findings from the previous chapters. The first concept incorporated into this model relies on the literature on risk perception and risk assessment. People perceive the actual risk based on their own risk attitude and determine safety behavior by comparing the perceived risk and internal standard of the risk tolerance (Hallowell 2010; Ji et al. 2011; Wang et al. 2016). The second concept incorporated into the model comes from theories in social science such as social comparison theory and social identity theory. People adjust their behaviors to conform to group norms that are shaped by interaction with others (e.g., observation and communication), and the influence of group norms depends on the salience of the group membership in their self-concept. The third concept built into the model reflects the empirical findings from the previous chapter (i.e., Chapter 3). The construction workers' safety behaviors can be predicted by their personal attitude, the perception of workgroup norm and management norm, and their social identification with the current project. The project identification positively moderates the relationship between management norm and safety behavior and negatively moderates the relationship between workgroup norm and safety behavior.

In this model, workers are provided with different work conditions and estimate the severity of the encountered risk (i.e., *Sensing*). The workers decide the safety behavior by comparing the perceived risk and their risk acceptance. The risk acceptance is influenced by individual's risk attitude and their interaction with others. Two types of *Interactions* are explicitly modeled in the model: (1) observing coworkers' behavior (source of the workgroup norm and descriptive norm); and (2) receiving managers' feedback on unsafe behavior (source of management norm and injunctive norm). Workers learn the acceptable risk at the current project by observing their coworkers' safety behavior in different risk conditions and managers' feedback on their unsafe behaviors. Also, workers adjust the risk attitude based on the result of their safety behavior (i.e., *Adoption and Learning*). If a worker experiences a near miss or accident after the unsafe behavior, the worker revises his/her risk attitude to be more risk-adverse. Lastly, *Stochasticity* is used when initializing risk attitude, risk perception coefficient (details of the risk perception is described in Section Submodels), and project identification, assigning the work conditions based on the site risk, establishing the risk acceptance based on the risk attitude, social norms, and salience of project identity, and whether the unsafe behavior results in a near miss in the model.

5.2.5 Submodels

The integration of safety decision-making processes and empirical findings regarding social influence on construction workers' safety behavior give us a chance to model a socio-cognitive mechanism of workers' safety behavior. A set of agent behavioral rules in the model is summarized in Figure 5.2.

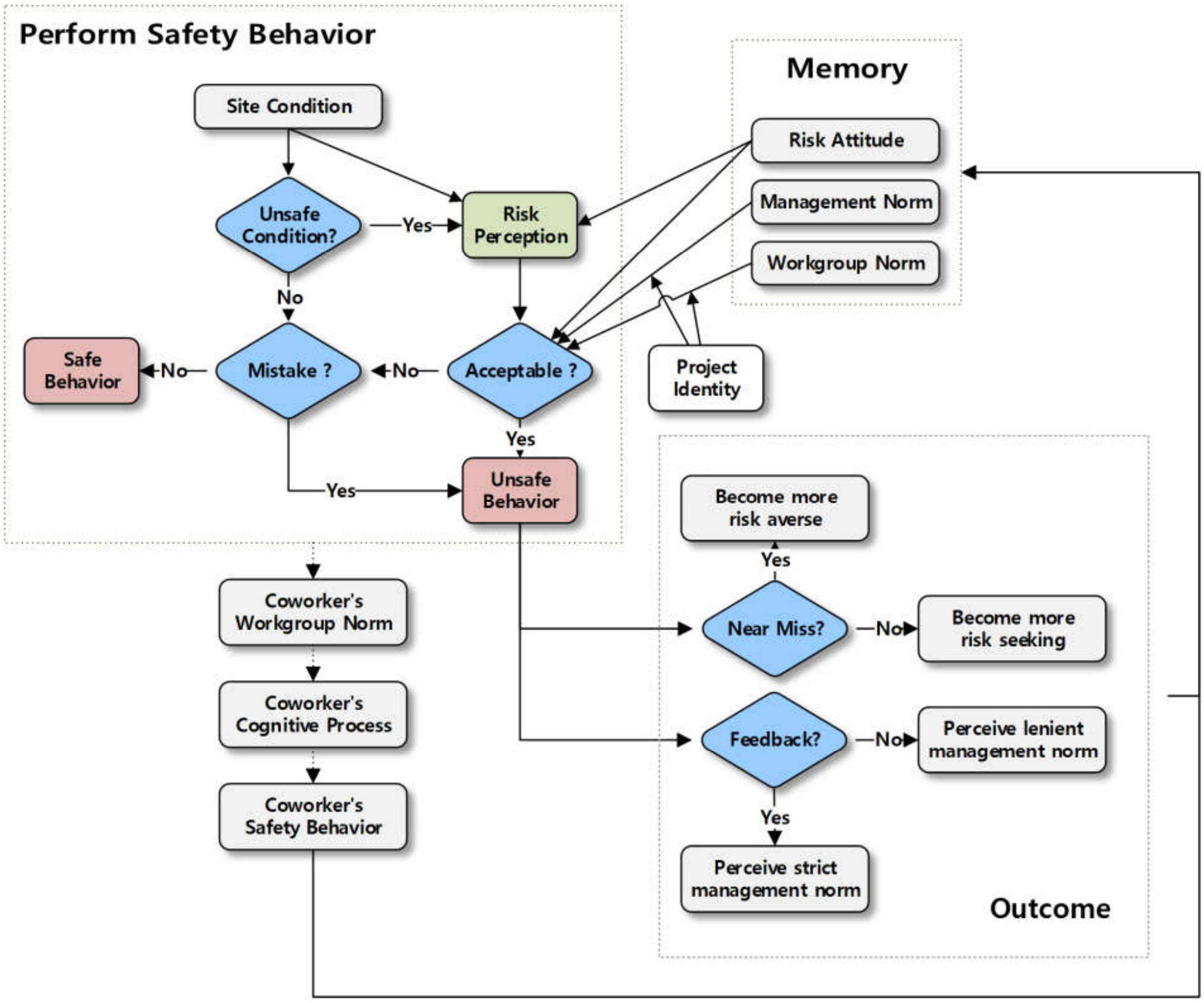


Figure 5.2 Agent Behavioral Rules

At the beginning of every time step, every worker is provided with a safe or unsafe work condition. The probability of being exposed to the unsafe condition and the risk level of the unsafe work condition is determined by the site risk. As an example, if the site risk is 0.5, the probability that a worker is under the unsafe condition is 0.5, and the average severity of the actual risk that a worker will be exposed is also 0.5. If a worker is under the safe condition and does not make a mistake, the worker shows a safe behavior. It should be noted that a mistake in this model does not refer to the human errors in the cognitive model of safety behavior. While the errors in the cognitive model refer to misjudgment or inappropriate decision in the cognitive process, mistakes in this model are not related to the cognitive process. The mistakes refer to mistaken actions during the action-taking phase. The mistake can happen without the cognitive process under the safe condition, and can also happen without errors in the cognitive process under the unsafe condition as explained below. If the worker makes a mistake, the worker performs an unsafe behavior. In the case of under the unsafe condition, the worker perceives the risk and make a decision regarding the perceived risk. The risk perception refers to an individual's subjective judgment and evaluation of the hazard that he/she is exposed (Hallowell 2010). As such, a worker's perceived risk might be different from another's even if both workers are exposed to the same actual risk. The subjective perceiving tendency is called as risk perception coefficient in the model, and it reflects an individual's tendency to underestimate or overestimate the risk. In the model, the risk perception coefficient is defined as the ratio of perceived risk to actual risk (Shin et al. 2014). An individual's risk perception coefficient is influenced by his/her risk attitude (Glendon and Walker 2013). As an example, if a worker has a risk adverse attitude (i.e., close to 0 in the model), the risk perception coefficient value is greater than 1.0 because the worker tends to overestimate the actual risk during the work. A worker's perceived risk and risk perception coefficient are calculated using Equations (1) and (2).

$$PR_i^{(t)} = p_i^{(t)} AR_i^{(t)} \tag{1}$$

$$p_i^{(t)} = p_i^{(t-1)} - (AT_i^{(t)} - (AT_i^{(t-1)}) \tag{2}$$

where $PR_i^{(t)}$ is worker i's perceived risk at time t, $AR_i^{(t)}$ is an actual risk that worker i encounters at time t, $p_i^{(t)}$ is worker i's risk perception coefficient at time t, and $AT_i^{(t)}$ is worker i's risk attitude at time t.

After perceiving the risk, the worker appraises the perceived risk and make a decision of safety behavior. The theory of risk homeostasis states that risk perception and acceptable risk are two main dimensions that determine the risk behavior (Wilde 1982). The perceived risk is behaviorally compensated if it exceeds an internal threshold (i.e., acceptable risk). In the model, if the perceived risk exceeds the worker's internal threshold which is defined as risk acceptance, the worker performs a safe behavior to prevent the accident. The risk acceptance varies because some workers are reluctant to tolerate the perceived risk while others are willing to accept the perceived risk. The results of Chapter 3 are incorporated to establish an equation of the risk acceptance. As shown in Equation (3), a worker's risk acceptance is a function of risk attitude, management norm, workgroup norm, project identification.

$$RA_i^{(t)} = (1-w)AT_i^{(t)} + w\left(pj_i MN_i^{(t)} + (1-pj_i)WN_i^{(t)}\right) + \epsilon \tag{3}$$

where $RA_i^{(t)}$ is worker i's risk acceptance at time t, $MN_i^{(t)}$ is worker i's management norm at time t, $WN_i^{(t)}$ is worker i's workgroup norm at time t, w is weight on social influence, pj_i is worker i's project identification, and ε represents the random fluctuation of the risk acceptance due to unexplained outside influence. The risk acceptance is affected by risk attitude, management norm, and workgroup norm, and the project identification intensifies the influence of management norm and attenuates the influence of workgroup norm on risk acceptance.

In the model, the workgroup norm is defined as an individual's perception of coworkers' risk acceptance and the extent to which individuals remember coworkers' behavior. The stored information is used in the process of perceiving social norms (Ahn et al. 2013). As such, the workgroup norm is represented as the weighted sum of the previous workgroup norm and the current perception of the average of coworkers' risk acceptance, as shown in Equation (4). Each worker's perception of a coworker's risk acceptance is the result of his/her observation of the coworker's safety behavior. As shown in Equation (5), if worker i observes coworker k's unsafe behavior, worker i interpret that coworker k performs unsafe behavior because k's risk acceptance is higher than the actual risk that k is exposed (Equation 5a). In the case of observing the safe behavior, worker i assumes that coworker k's risk acceptance is lower than the actual risk that coworker k encounters (Equation 5b).

$$WN_i^{(t)} = \left(1-\frac{1}{m}\right)WN_i^{(t-1)} + \frac{1}{m}\left(\frac{1}{k_i^{(t)}}\sum_{k=1}^{k_i^{(t)}} PRA_{ik}^{(t)}\right) \tag{4}$$

$$PRA_{ik}^{(t)} = \begin{cases} Rand\left(AR_k^{(t)}, 1\right)\ (if\ UB_k^{(t)} = 1) & \text{(5a)} \\ Rand\left(0, AR_k^{(t)}\right)\ (if\ UB_k^{(t)} = 0) & \text{(5b)} \end{cases}$$

where $PRA_{ik}^{(t)}$ is worker i's perception of coworker k's risk acceptance at time t, $UB_k^{(t)}$ is worker k's unsafe behavior at time t (0 = safe behavior), m is individual's memory capacity, $k_i^{(t)}$ is number of coworkers who are under the unsafe condition and around worker i at time t.

The management norm refers to an individual's perception of managers' risk acceptance in the model. The management norm is also defined as the weighted sum of previous management norm and current perception of managers' risk acceptance, as shown in Equation (6). The current perception of managers' risk acceptance is the results of the individual's experience of feedback on his/her unsafe behaviors from managers. If worker i performed a safe behavior at the previous time step, i does not have a chance to adjust the management norm (Equation 7a). If worker i received feedback on the unsafe behavior at the previous time step, i interprets that risk acceptance of manager at the current project is lower than his/her perceived risk (Equation 7b). On the other hand, if worker i did not receive any feedback from managers even if i performed an unsafe behavior, i assumes that the perceived risk is acceptable in the current project (Equation 7c).

$$MN_i^{(t)} = \left(1 - \frac{1}{m}\right) MN_i^{(t-1)} + \frac{1}{m}\left(PMA_i^{(t)}\right) \tag{6}$$

$$PMA_{ik}^{(t)} = \begin{cases} MN_i^{(t-1)}\ (if\ UB_i^{(t-1)} = 0) & \text{(7a)} \\ Rand\left(0,\ PR_i^{(t-1)}\right)\ (if\ UB_i^{(t-1)} = 1, MF_i^{(t-1)} = 1) & \text{(7b)} \\ Rand\left(PR_i^{(t-1)}, 1\right)\ (if\ UB_i^{(t-1)} = 0,\ MF_i^{(t-1)} = 0) & \text{(7c)} \end{cases}$$

where $PMA_i^{(t)}$ is worker i's perception of managers' risk acceptance at time t, $MF_i^{(t)}$ is managers' feedback on worker i's unsafe behavior at time t (0 = no feedback).

If the perceived risk is higher than risk acceptance, which means the perceived risk is not acceptable, and the worker does not make a mistake, the worker performs the safe behavior. Otherwise, the worker will perform an unsafe behavior, and it leads to either near miss or nothing. The probability of the near miss is reckoned base on the actual risk which is drawn from the site risk. If the worker experiences the near miss, the worker adjusts the risk attitude to be more risk averse because the worker becomes aware of the possibility of the accident. On the other hand, if nothing happens, the experience makes the worker underestimate the possibility of the accident and become more risk-seeking (i.e., optimistic recovery (Shin et al. 2014)). Also, the worker's unsafe behavior can receive feedback from managers. The probability of the feedback is determined by the strictness and frequency of management feedback. If the actual risk, that the worker experiences, is lower than managers' risk acceptance which means the risk is acceptable to the managers, the worker does not receive feedback from managers even if the worker performs the unsafe behavior. If the actual risk is unacceptable to the managers (i.e., the actual risk is higher than managers' risk acceptance), the probability of the feedback is determined by the frequency of management feedback that is determined when the model is initialized. Then, the worker adjusts the strictness of management norm based on the experience of management feedback as described in Equation 7. The feedback processes in the model should be noted. As shown in Figure 2, the outcomes of the safety behavior (i.e., near miss occurrence and feedback from managers) would be sources of risk attitude and management norm at the next time step. Also, a worker's safety behavior would be a source of their coworker's workgroup norm and results in coworker's safety behavior. Then, the coworker's safety behavior, in turn, will be the source of the worker's workgroup norm.

5.2.6 Initialization

The model initializes a 200-worker project, which consists of twenty workgroups and each of workgroup has ten workers. At the beginning of each simulation run, workers are initialized with assigning different values to the parameters representing their attributes such as risk attitude and risk perception coefficient to reflect individuals' heterogeneity. First, it is assumed that the parameters follow a uniform distribution because the uniform distribution is most appropriate to assume when nothing is known about the distribution (Bruch and Atwell 2015). The range of risk attitude is determined from 0.1 to 0.9 in order to exclude extremely risk averse or risk seeking attitude. Also, the risk perception coefficient is assigned based on the uniform distribution from 0.6 to 1.2. The mean of the risk perception coefficient is determined to be less than 1.0 in order to reflect construction workers' tendency to underestimate the actual risk and overestimate their ability to control the environment (Zhang and Fang 2013; Wang et al. 2016). The minimum value of the range of the risk perception coefficient (i.e., 0.6) is determined based on the result of Shin et al. (2014).

Every worker in the model creates the perception of workgroup norm and management norm based on the observation of coworkers' behavior and managers' feedback stored in the memory to make a decision regarding safety behavior. Workers in the model remember 15 days of coworkers' behaviors and managers' feedback and use the stored information in creating workgroup norm and management norm. Workers in the model should put forth some effort (i.e., cost) to learn from others (i.e., observing coworkers) to form their workgroup norm (i.e., social learning or social interaction). Also, the cost of observing coworkers' behavior within the workgroup may not be the same as the cost of observing across workgroups due to the different distances between the observations. To reflect these differences, the probabilities of the social interaction within the workgroup and across workgroups vary in the model. Within each workgroup, every worker is able to observe other workers (i.e., clique) whereas social interaction across the workgroups is limited (i.e., a sparse network) (Ahn et al. 2013). The value of weight on social influence is determined by the ratio of the standardized regression coefficient of personal attitude to that of social influence (i.e., workgroup norm and management norm) in Chapter 3. The initial values of the project state variables (i.e., site risk, strictness of management feedback, and frequency of management feedback) can be changed based on the characteristics of the project. For the baseline model, the site risk is set to a moderate level (= 0.5). The management risk acceptance is assigned based on the uniform distribution from 0.2 to 0.4 because construction managers have somewhat strict safety norms as shown in Chapter 2 and Chapter 3, and the management feedback frequency is set to 0.7. In other words, 70% of workers who perform unsafe behavior under the condition in which the actual risk is greater than management risk acceptance (i.e., uniform [0.2, 0.4]) receive the feedback from managers in the baseline model. Lastly, workers' project identification is assigned based on the uniform distribution from 0.1 to 1.0 to reflect individuals' heterogeneous project identity.

5.3 VALIDATION

One of the crucial stages in developing a simulation model is to determine whether a developed model is an accurate presentation of the real system (i.e., model validation) (Ormerod and Rosewell 2009). In this regard, Zeigler et al. (2000) distinguished three different kinds of validity: replicative validity (i.e., the model "matches data already acquired from the real system"), predictive validity (i.e., the model "matches data before data acquired from the real system"), and structural validity (i.e., the model "truly reflects the way in which the real system operates"). Also, the validity of a simulation model should be tested with respect to the purpose of the model (Sargent 2000; Gilbert 2008). The main objective of the developed model is to provide insight into the role of socio-cognitive mechanism in construction workers' safety behavior not to make an accurate pinpoint prediction of the safety behavior. As such, the validation process focused more on replicative and structural validity.

From the perspective of replicative validity, Axtell and Epstein (1994) categorized the performance of ABM based on how accurately the model can replicate the reality. Axtell and Epstein (1994)'s classification has four performance levels based on two different dimensions (i.e., qualitative-quantitative replication and replication of macro-micro level structure (i.e., group-individual level behavior)). The lowest level of model performance (i.e., Level 0) is achieved when "the agent behavioral rules is in qualitative agreement of the micro-behavior." Level 1 is present when "the model behavior is in qualitative agreement with empirical macro-structures." Level 2 is achieved when "the model behavior is in quantitative agreement with empirical macro-structures." The highest level (i.e., Level 3) is achieved "when the model is in quantitative agreement with empirical micro-structures." Based on the classification, Ahn and Lee (2015) proposed a methodology to create empirically supported ABM with survey data for studying construction workers' group behaviors. Among the classification, the agent-based model in this paper aims to achieve Level 2 because "Level 3 would not be realistic in the human behavior simulation due to the inherent uncertainty in the human behavior and the random events in reality" (Ahn and Lee 2015). Therefore, qualitative and quantitative agreements between the simulation results from the baseline model and the empirical macro-structures were examined to validate the simulation model. Therefore, qualitative and quantitative agreements between the simulation results from the baseline model and the empirical macro-structures were examined to validate the simulation model. In other words, the replicative validity of the model is examined by testing whether the model reproduces the phenomena that previous empirical studies and safety statistics observed. The results from previous empirical studies regarding the macro-structure of the system are compared to the simulation results to examine the qualitative agreements of the model. Also, the quantitative agreement is examined by comparing the incident rate from the baseline model and the national non-fatal injury rate.

First, the relative strictness of workgroup norm, management norm, and an individual's risk acceptance is compared. Figure 5.3 shows the changes in the mean of workgroup norm, management norm, and an individual's risk acceptance over time in the baseline model. In Figure 5.3, the horizontal axis refers to time steps in the simulation and the vertical axis represents the acceptable risk level of workgroup norm, management norm, and an individual's risk acceptance. As shown in Figure 5.3, the workgroup norm has the higher risk acceptance than management norm (i.e., the workgroup norm is more lenient than the management norm), and an individual's risk acceptance stands between the workgroup norm and management norm. The results reproduce the empirical findings from Chapter 2 and Chapter 3.

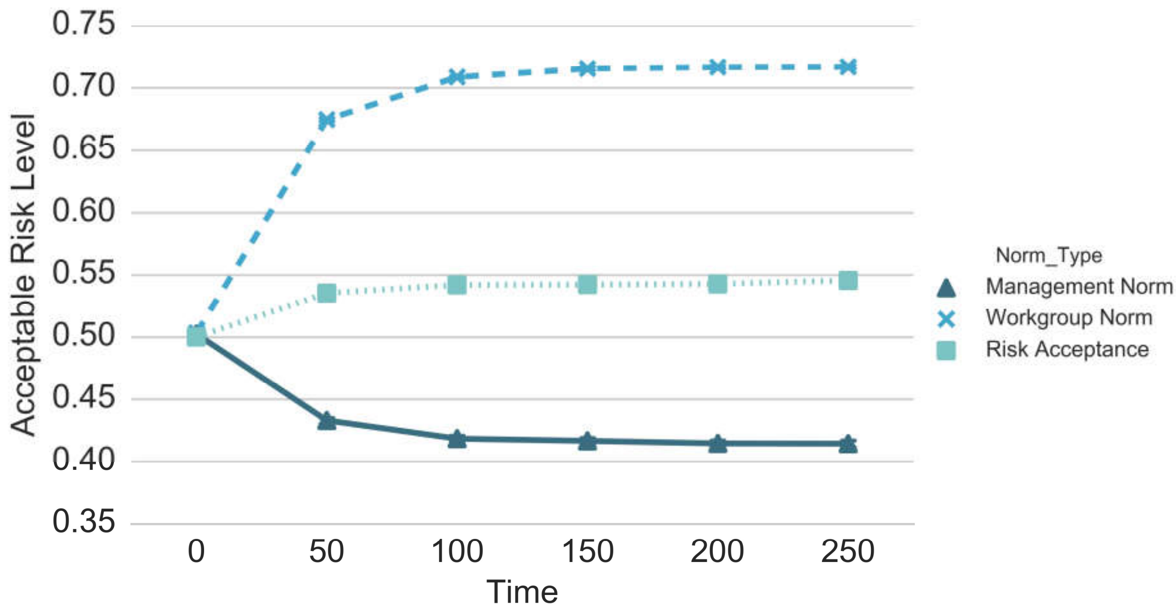


Figure 5.3 Changes in Workgroup Norm, Management Norm, and Risk Acceptance in the Baseline Model

The simulation results also reaffirm the role of personal attitude in risk acceptance as well as safety behavior in previous studies (Zhang and Nuttall 2011; Goh and Binte Sa'adon 2015; Wang et al. 2016). Figure 5.4 describes the relationship between risk attitude and risk acceptance in the result of the baseline model. The horizontal axis refers to risk attitude and the vertical axis indicates risk acceptance. As shown in Figure 5.4, there is a significant and positive correlation between risk attitude and risk acceptance ($\rho = .483$, $p < .001$). As a worker shows risk seeking attitude (i.e., closer to 1), the worker has higher level of risk acceptance which means more tolerate the risk during the work.

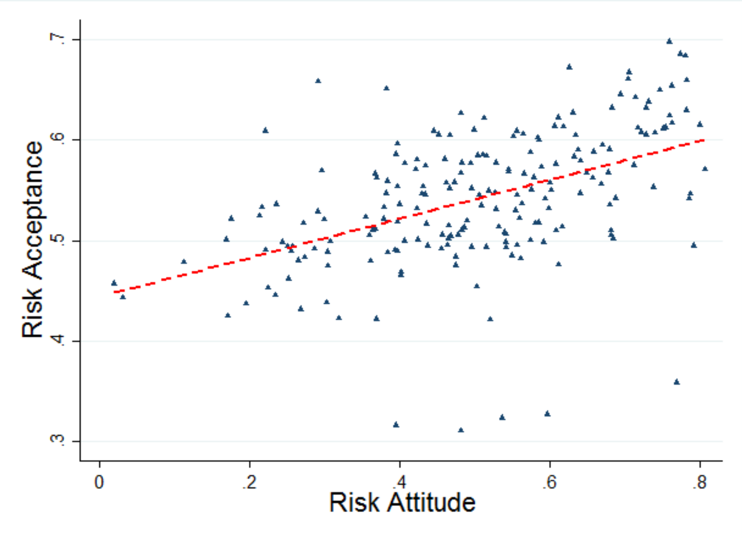


Figure 5.4 Relationship between Risk Attitude and Risk Acceptance in the Baseline Model

The baseline model also effectively reproduces the phenomena that workers' safety behaviors are under the influence of interaction with coworkers and management (Choudhry and Fang 2008; Meliá et al. 2008; Brondino et al. 2012; Fang et al. 2015). Also, the simulation results provide evidence on how the project identity moderates the relationship between social norms and risk acceptance. In Chapter 3, it was observed that workers, who are strongly identified with their project, are more likely to be influenced by positive interaction with their managers and less influenced by negative interaction with coworkers. Using the baseline model above, the model is able to reproduce this macro-level behavioral pattern. As shown in Figure 5.5, high project identity group (i.e., project identification is greater than 0.5) in the baseline model exhibits a steeper regression slope between management norm which means a positive interaction between project identification and management norm. The opposite effect is observed for the relationship between workgroup norm and project identification.

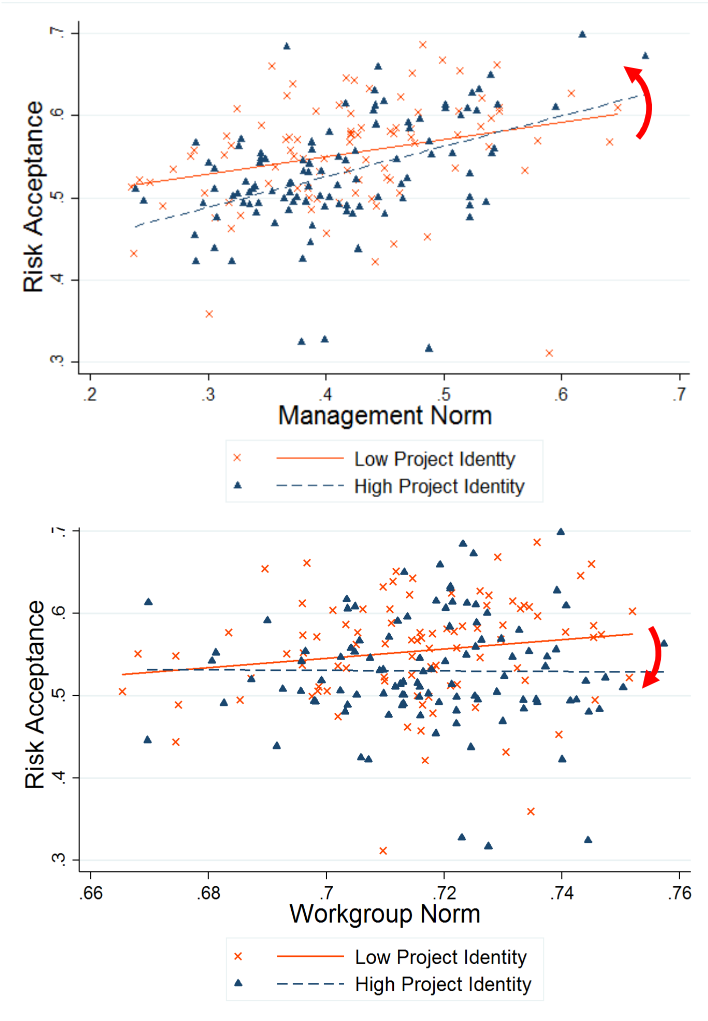


Figure 5.5 Interaction between Project Identity and Social Norms in the Baseline Model

In addition to the qualitative agreement (i.e., Level 1), this paper also examines the quantitative agreements between the simulation results and empirical data (i.e., Level 2). For the comparison, the baseline model was run 50 times, and the mean of unsafe behavior ratio was calculated to compare with the empirical data from previous studies. The mean of unsafe behavior ratio was 0.34 (standard deviation = 0.035) that is consistent with previous findings from Sa et al. (2009), and Fang and Wu (2013). Both studies noted that one-third of workers did not actually behave safely at the construction site. Also, the incident rate of each simulation run was calculated based on Heinrich triangle (Heinrich et al. 1950). The triangle proposed that for every major accident there are 29 minor accidents and 300 near misses (i.e., 300 (near miss) – 29 (minor accident) – 1 major accident). Base on the ratio between near misses and accidents (major and minor accidents) in the triangle (300: 30), the incident rate of each calculation is calculated. The mean of the 50 simulation runs of the baseline model was 3.45 (SD = 0.535) which is very similar to the incident rate of nonfatal occupational injuries in the construction in 2015 (= 3.50, U.S. BLS 2016c). Therefore, it was demonstrated that the results of the baseline model exhibit quantitative agreement with the empirical group-level safety behaviors (i.e., Level 2).

Several methods were employed to enhance the structural validity of the model. First, the construction of the model builds upon the established and validated theories from social science literature (e.g., social comparison theory and social identity theory) to describe how the interactions between construction workers' cognitive process and the environment (i.e., site condition, coworkers, and managers) produce safety behaviors. Also, the extreme-value testing and unit-testing were conducted and verified the model and submodels during the model development. Moreover, values and ranges of input parameters (e.g., weight of social influence, risk perception coefficient, management risk acceptance, etc.) in the model were determined by the observations and empirical findings from previous studies and further tested by the sensitivity analysis as discussed in Section Method. Lastly, a distinguished scholar who published seven books and more than 80 journal articles in the field of complex systems evaluated whether assumptions and outputs of the model are reasonable and plausible to enhance face validity of the model. All the aforementioned techniques are well established and recognized methods to test the structural validity of the simulation model (Balci 1998; Klügl 2008; Law 2013).

5.4 EXPERIMENTS

In order to examine how workers' socio-cognitive process of safety behavior responds to different safety management strategies and produces safety behavior, impacts of three parameters (i.e., strictness and frequency of management feedback and project identity) on project-level safety behaviors were investigated. Those three parameters represent possible managerial strategies to improve workers' safety behaviors at a construction site. To reduce workers' unsafe behaviors, management could have stricter risk acceptance (i.e., strictness of management feedback) and more frequently observe workers' behaviors and provide safety feedback on unsafe behaviors (i.e., frequency of management feedback). Also, management could make workers more aligned with management norms by promoting their project identification (i.e., project identity). The impacts of these parameters were tested by applying different values in the model and comparing the simulation results (i.e., parameter sweep). The range of strictness of management feedback was determined from 0.5 to 0.9 because excessively lenient risk acceptance of the management does not reflect practices in safety management. It is observed that construction workers already perceived somewhat strict management norms in the current project as shown in Chapter 2 and 3. Also, the frequency of the management feedback has the range of value from 0.5 to 0.9, thus excluding excessively infrequent feedback from management. Lastly, the project identity had a relatively broad range of value (i.e., from 0.1 to 0.9) in the experiment.

In addition to the different safety management strategies, different site conditions (e.g., site risk) also could be a source of interaction with the socio-cognitive process of workers' safety behavior. Therefore, the parameter sweeps were repeated in three different site risks (i.e., low-risk (0.25), moderate-risk (0.5), and high-risk (0.75)) to explore the effect of interaction between the socio-cognitive process and different site conditions on safety behavior. The three site risk conditions in the experiment represent the characteristics of the projects with respect to the risk. In reality, all construction projects do not have the same severity of potential hazards because of different attributes of the project. For instance, suppose that there are two high-rise buildings with the same design and other conditions (e.g., location, general contractor, etc.), but one is a reinforced concrete building while the other is a precast concrete building. Workers in the second project (i.e., precast concrete building) are less likely to be exposed to hazards than workers in the first project (i.e., reinforced concrete building) because risky activities such as rebar placement and formwork are executed in the controlled factory. As such, the experiment to examine the interaction between the three managerial interventions and three site risk conditions provides construction practitioners with more insights into how to develop effective safety management plans in different projects. As aforementioned above, the site risk includes the likelihood of workers being exposed to an unsafe condition and the average severity of the actual risk of the unsafe conditions in the model. The actual risk is assigned based on the beta distribution which is defined as a continuum between 0 and 1. As shown in Figure 5.6, the severity of actual risk in the low-risk site condition shows a positively skewed distribution while the high-risk site condition has a negatively skewed distribution. Each set of conditions (i.e., strictness, frequency, project identity, and site risk) was simulated thirty times to produce a sufficiently large sample.

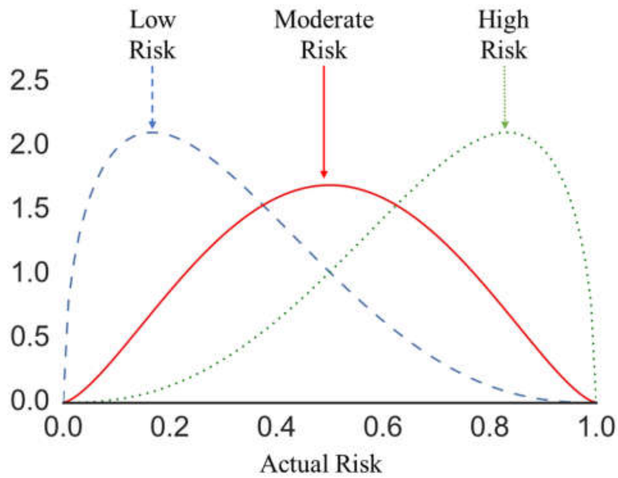


Figure 5.6 Distribution of Actual Risk in the Three Site Risk Conditions

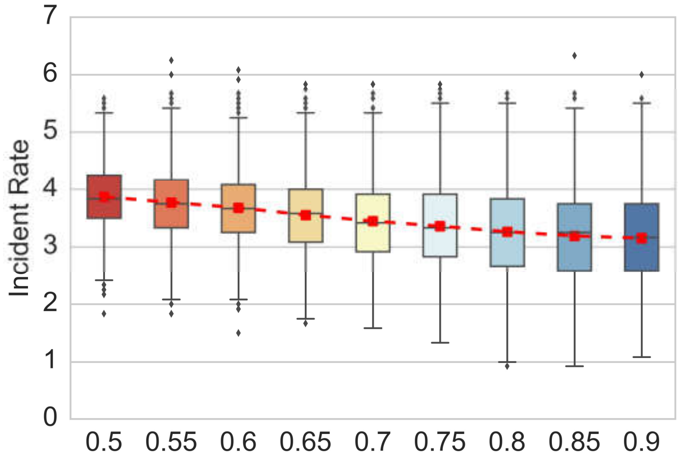
5.5 RESULTS

In total, 65,610 simulation runs were run to explore the effects of the interaction between workers' socio-cognitive process and the three safety management interventions across three different site conditions. Statistical differences between the variables of interest are examined using Mann–Whitney U test because assumptions for the parametric statistical test (e.g., normality assumption) could not be met. To examine the effects of the three interventions, differences in the incident rate between low and medium level and between the medium and high level of the interventions are examined. For the strictness and frequency of the management feedback, 0.5 is determined as low level, 0.7 as medium level, and 0.9 as high level. For the project identity, 0.2 is set as low level, 0.5 as medium level, and 0.8 as high level. To address false-positive errors associated multiple uses of the medium level for the comparisons, the results of Mann–Whitney *U* test were corrected by Bonferroni correction. Also, the effects of interactions between the interventions were analyzed using factor plots.

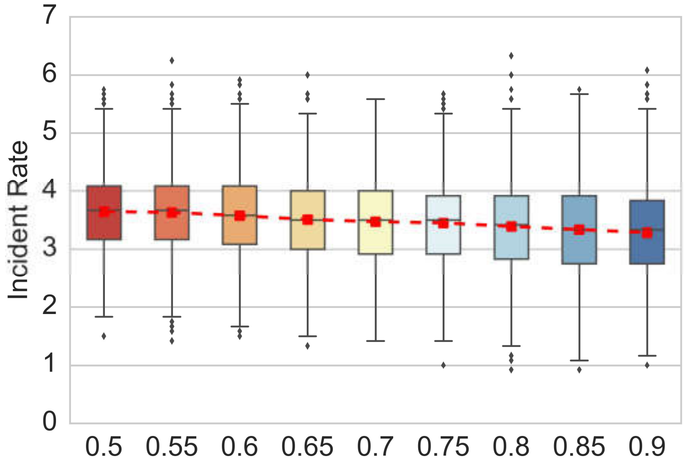
The direct effects of the three interventions in the moderate-risk condition can be seen in Figure 5.7. In Figure 5.7, the horizontal axes represent changes in the value of the three interventions, and the vertical axes refer to the incident rate. As shown in Figure 5.7, all the interventions contribute to reducing the incident rate. First, there are significant differences in the incident rate between low (Mdn = 3.833) and medium level of strictness (Mdn = 3.417), U =

1,913,773.0, $p = 3.19 \times e^{-100}$, and between medium (*Mdn* = 3.417) and high level of strictness (*Mdn* = 3.167), $U = 2{,}354{,}768.0$, $p = 2.24\times e^{-34}$ (Figure 5.7 (a)). Also, more frequent feedback from the management makes a marked improvement on the incident rate (Low (*Mdn* = 3.667) and Medium (*Mdn* = 3.500), $U = 2{,}556{,}083.0$, $p = 5.07 \times e^{-16}$; Medium (*Mdn* = 3.500) and High (*Mdn* = 3.333), $U = 2{,}574{,}759.0$, $p = 1.11 \times e^{-14}$, Figure 5.7 (b)). The project identity has a statistically significant and meaningful impacts on decreasing the incident rate (Low (*Mdn* = 3.917) and Medium (*Mdn* = 3.500), $U = 1{,}674{,}181.0$, $p = 8.04 \times e^{-151}$; Medium (*Mdn* = 3.500) and High (*Mdn* = 2.917), $U = 1{,}639{,}689.5$, $p = 6.53 \times e^{-159}$, Figure 5.7 (c)).

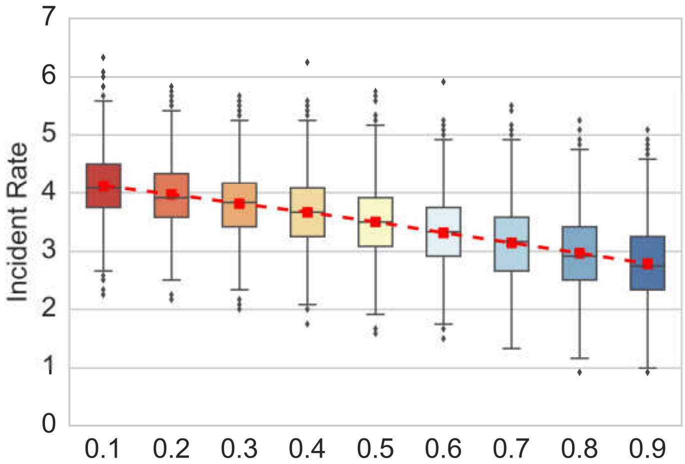
Figure 5.8 shows the effects of interactions between the interventions on the incident rate in the moderate site risk condition. For example, Figure 5.8 (b) represents changes in the incident rate along with project identity in the three strictness values. In Figure 5.8 (b), differences between the three lines at a specific value of project identity implies effects of the strictness on the incident rate at the same value of the project identity. As such, a strong interaction between project identity and strictness can be found in Figure 5.8 (b) because the differences between the three lines (i.e., the effect of strictness on the incident rate) significantly increase as the project identity increases. In other words, the effect of the strictness on the incident rate is intensified by the project identity. On the other hand, relatively weak interactions are found between the strictness and frequency (Figure 5.8 (a)) and between project identity and frequency (Figure 5.8 (c)).



(a) Strictness

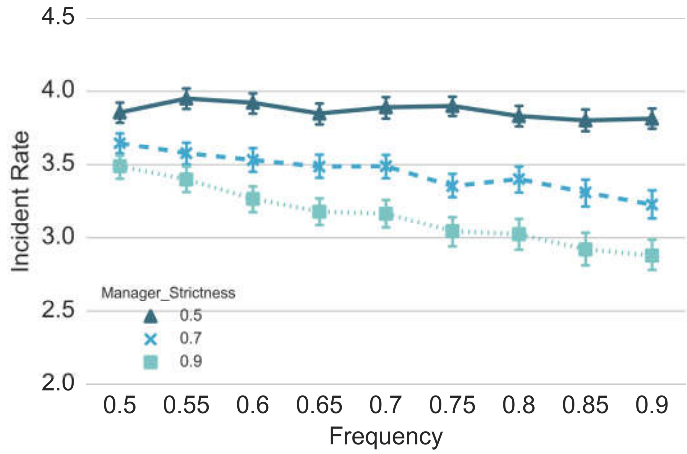


(b) Frequency

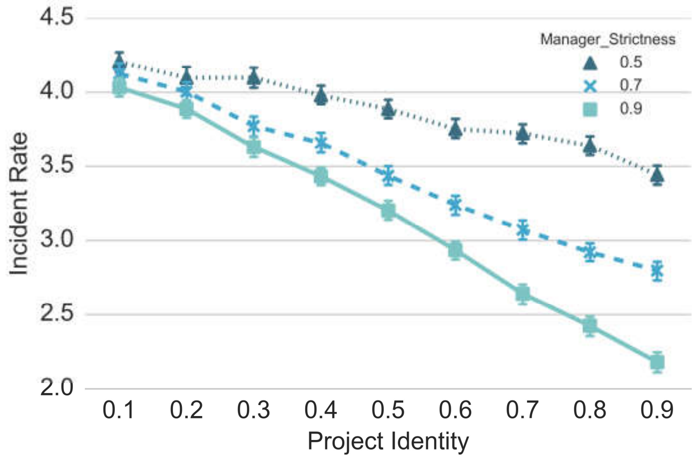


(c) Project Identity

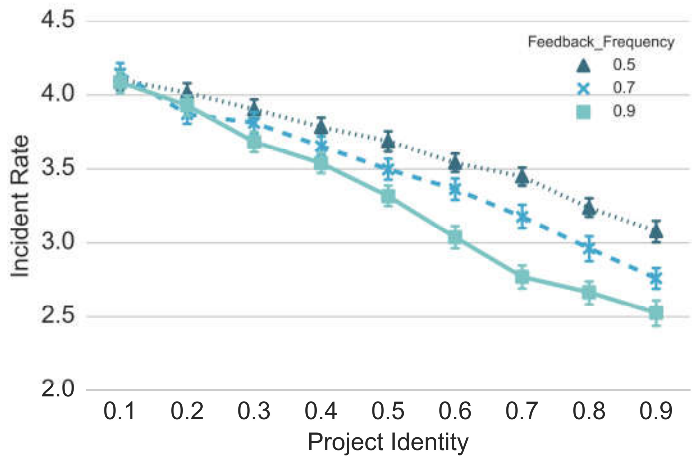
Figure 5.7 Direct Effects of the Interventions in Moderate Site Risk



(a) Strictness & Frequency



(b) Strictness & Project Identity

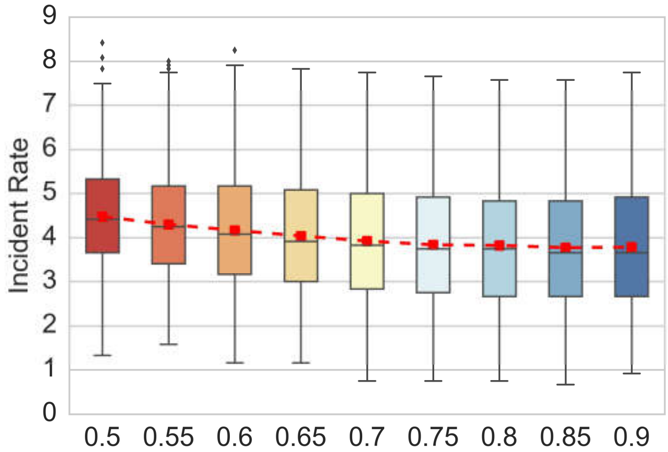


(c) Frequency & Project Identity

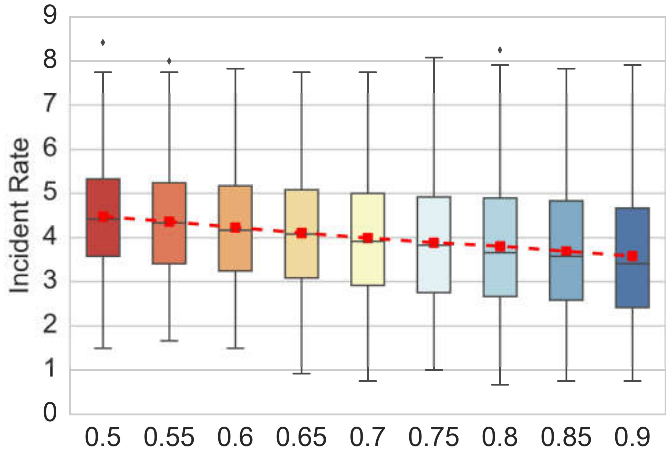
Figure 5.8 Effects of Interactions between the Interventions in Moderate Site Risk

Figure 5.9 and Figure 5.10 represent effects of the three interventions on the incident rate in the high-risk condition. As shown in Figure 5.9, all the three interventions also directly decrease the incident rate in the high-risk condition. The median of the incident rate in low, medium, and high strictness varies significantly and exhibit meaningful differences (Low (*Mdn* = 4.417) and Medium (*Mdn* = 3.833), $U = 2{,}234{,}235.5$, $p = 7.73 \times e^{-49}$; Medium (*Mdn* = 3.833) and High (*Mdn* = 3.667), $U = 2{,}774{,}106.0$, $p = 2.65\times e^{-4}$, Figure 5.9 (a)). Also, there are significant differences in the median of the incident rate between low (*Mdn* = 4.417) and medium frequency (*Mdn* = 3.917), $U = 2{,}315{,}294.5$, $p = 8.26 \times e^{-39}$ and between medium (*Mdn* = 3.917) and high frequency (*Mdn* = 3.417), $U = 2{,}448{,}861.0$, $p = 7.17\times e^{-25}$, Figure 5.9 (b)). Lastly, the project identity has a significant impact on the incident rate (Low (*Mdn* = 5.417) and Medium (*Mdn* = 3.917), $U = 373{,}146.0$, $p \approx .00$; Medium (*Mdn* = 3.917) and High (*Mdn* = 2.667), $U = 672{,}480.0$, $p \approx .00$, Figure 5.9 (c)).

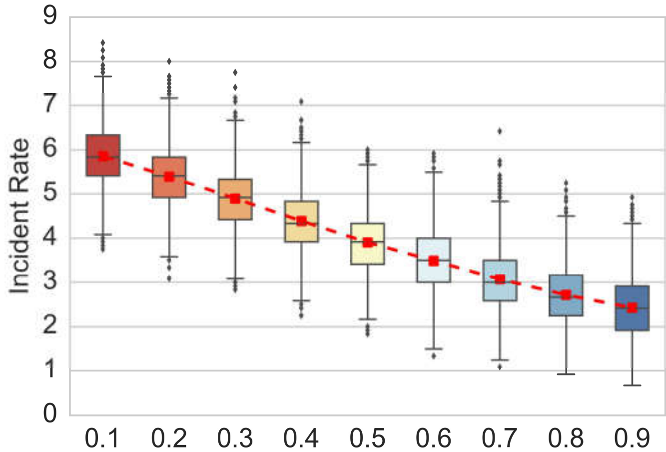
Figure 5.10 provides a deeper understanding of the effects of the interventions. In Figure 5.10 (a) and 5.10 (b), a distance between the line of 0.5 strictness and 0.7 strictness is much greater than a distance between 0.7 strictness and 0.9 strictness. It implies that the effects of the strictness on the incident rate become diminished as the strictness increases. On the other hand, the frequency of management feedback and project identity have relatively stable effects on the incident rate because all the lines in Figure 5.10 (a) and 5.10 (b) have linear patterns. While there are significant interactions between strictness and project identity and between frequency and project identity, the interaction between strictness and frequency is not significant because all the three lines in Figure 5.10 (a) are quite parallel.



(a) Strictness

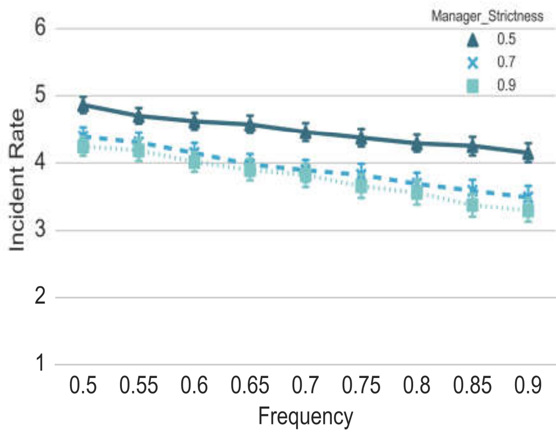


(b) Frequency

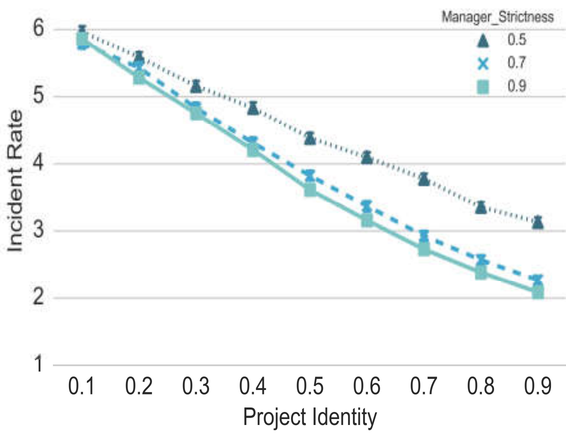


(c) Project Identity

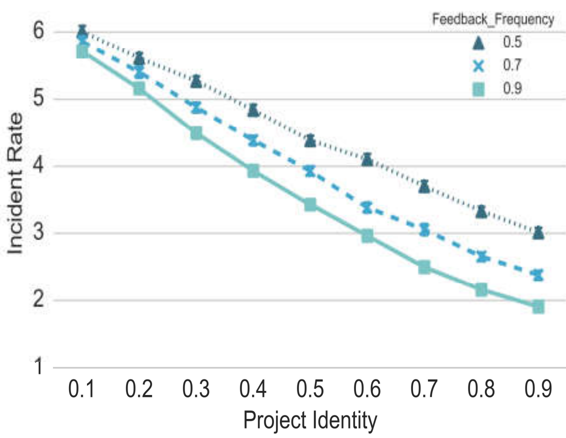
Figure 5.9 Direct Effect of the Interventions in High Site Risk



(a) Strictness & Frequency



(b) Strictness & Project Identity

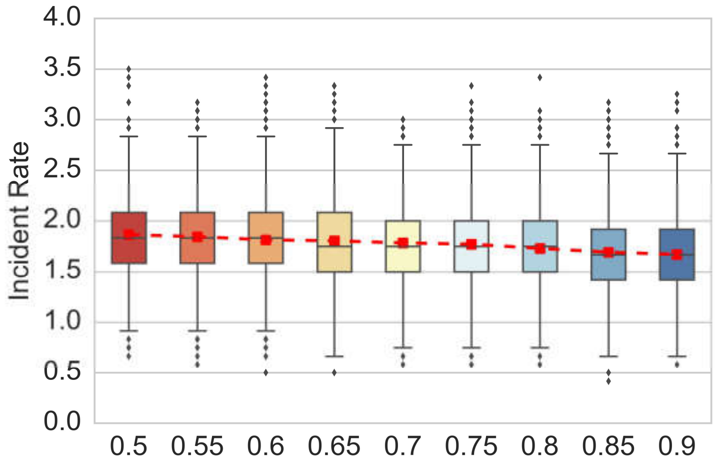


(c) Frequency & Project Identity

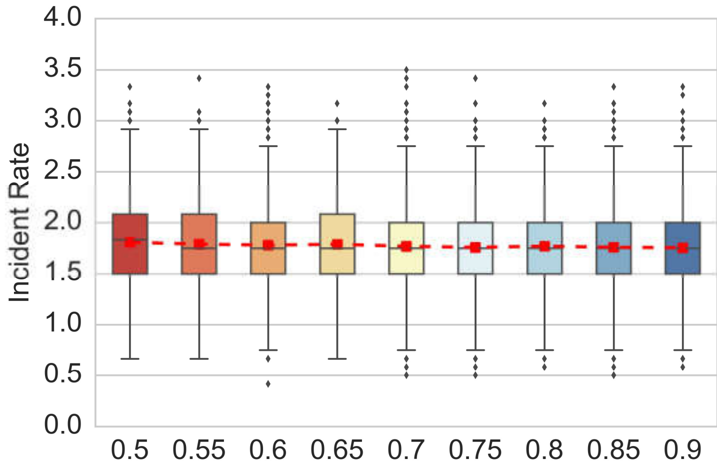
Figure 5.10 Effects of Interactions between the Interventions in High Site Risk

Lastly, the results in the low-risk condition are presented in Figure 5.11 and Figure 5.12. As shown in Figure 5.11, all the three interventions in the low-risk condition have relatively weaker effects on the incident rate than in medium and high-risk condition. The strictness has a statistically significant and meaningful effect on the incident rate (Low (*Mdn* = 1.833) and Medium (*Mdn* = 1.750), U = 2,623,258.5, $p = 1.53 \times e^{-11}$; Medium (*Mdn* = 1.750) and High (*Mdn* = 1.667), U = 2,774,106.0, $p = 7.04\times e^{-24}$, Figure 5.11 (a)). While there are significant differences in the median of the incident rate between low (*Mdn* = 1.833) and medium frequency (*Mdn* = 1.750), U = 2,785,638.0, $p = 0.001$, the differences between medium (*Mdn* = 1.750) and high frequency (*Mdn* = 1.750) are not significant, U = 2,892,484.0, $p = 0.23$ (Figure 5.11 (b)). Lastly, the median of the incident rate was found to be significantly different foe each level of project identity (Low (*Mdn* = 1.833) and Medium (*Mdn* = 1.750), U = 2,787,591.0, $p = 0.001$; Medium (*Mdn* = 1.750) and High (*Mdn* = 1.667), U = 2,568,234.5, $p = 3.47\times e^{-15}$, Figure 5.11 (c)).

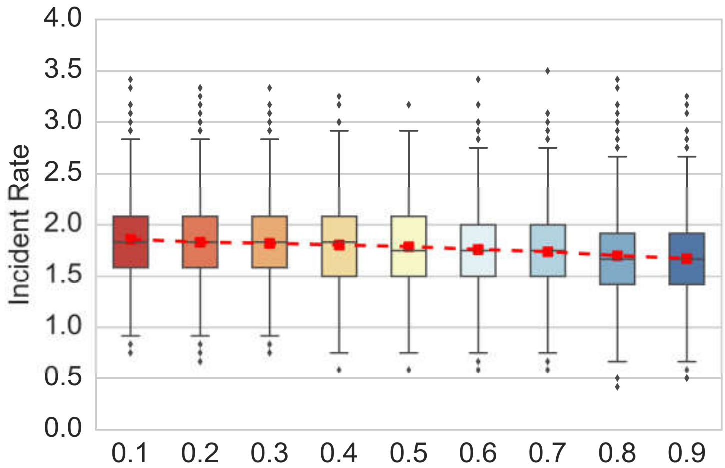
Figure 5.12 represents the effects of interaction between the interventions in the low site risk condition. As shown in Figure 5.12, no significant interactions are found in Figure 5.12 with the exception an interaction between project identity and high level of strictness (i.e., strictness = 0.9).



(a) Strictness

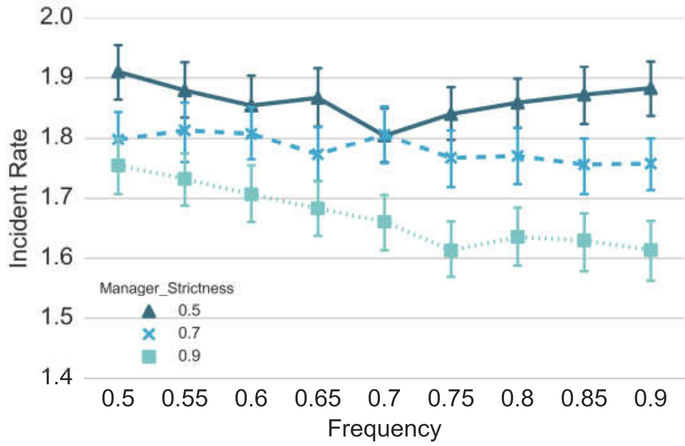


(b) Frequency

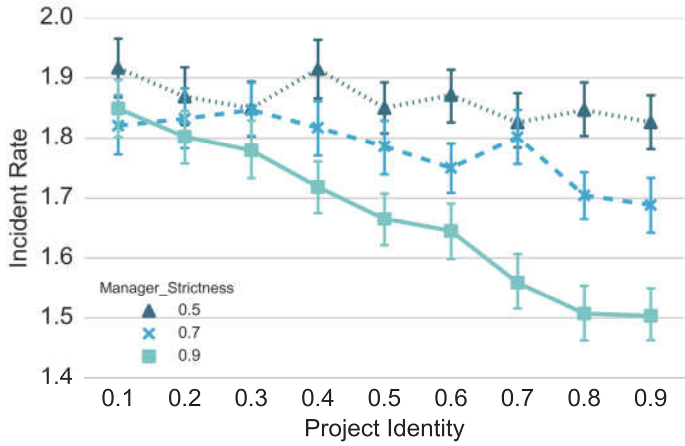


(c) Project Identity

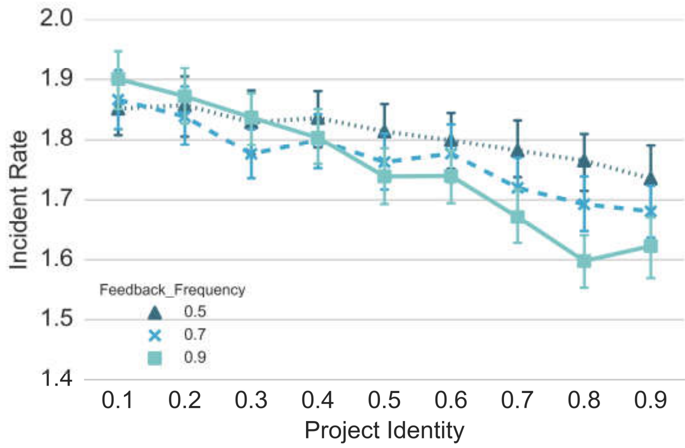
Figure 5.11 Direct Effect of the Interventions in Low Site Risk



(a) Strictness & Frequency



(b) Strictness & Project Identity



(c) Frequency & Project Identity

Figure 5.12 Effects of Interactions between the Interventions in Low Site Risk

5.6 DISCUSSION

The model presented in this chapter simulates workers' socio-cognitive process of safety behavior and its interaction with the environment (i.e., coworkers, management, and site condition) using theories from the literature and findings from an empirical study in the previous chapter. This chapter extends the validity of the model by examining the qualitative (i.e., Level 1) and quantitative agreement (i.e., Level 2) between the simulation results of the baseline model and empirical macro-level structure. The validity of the model would be more critical when the simulation model has "a pragmatic purpose such as providing assistance to decision makers to better manage human resource" (Ahn and Lee 2015). In this regard, there has been an increasing interest in creating an empirically grounded agent-based model of human behavior (Janssen and Ostrom 2006). The model presented in this chapter is in line with these efforts and extends the knowledge of agent-based modeling research methodology. Also, the model provides insights into how workers interact with and make sense of their environment (i.e., coworkers, managers, and site risk) and perform safety behaviors in the construction projects. Lastly, the results of the experiments could be a means of developing effective safety management strategies/interventions to improve workers' safety behaviors at the group level in different site conditions.

With the model validated against empirical data from previous studies and statistics, it was used to examine the effectiveness of the three safety management interventions on the incident rate across the three different site risk conditions. The three safety management interventions include stricter and more frequent management feedback on workers' unsafe behaviors and fostering workers' social identification with their project. The three managerial interventions were selected because they could be widely applied to construction projects. First, stricter management feedback means managers in the project have a stricter standard to workers' unsafe behaviors. In other words, managers in the project do not turn a blind eye to workers' unsafe behavior even when the risk posed is minimal. To achieve such standards, it is important that all the managers who interact with workers at the site (i.e., safety managers, supervisors, foremen, construction engineers, etc.) have a consistent response to the unsafe behaviors. Safety training programs for other types of managers would be an effective means to improve the strictness of management norms. Second, more frequent management feedback refers to workers having more chances to be observed and receive feedback from managers with respect to their unsafe behaviors. However, increasing the number of safety managers in the project may not be practical due to the limited budget for the project. As such, not only safety managers but also other types of managers should pay more attention to safety at the site to increase the frequency of management feedback. Lastly, promoting workers' project identification was selected based on the result from the previous chapters. As the workers strongly identify with their project, they are more likely to internalize and adhere to management norm. In this regard, several studies have identified antecedents of employee's organizational identification such as perceived prestige (Bergami and Bagozzi 2000; Carmeli 2005), leadership style (Sluss et al. 2008; Walumbwa et al. 2008; Walumbwa et al. 2011), communication style (Nakra 2006; Bartels et al. 2007) and suggest practical methods to promote employees' organizational identification (Peters et al. 2013).

The results of the experiment showed that all the three interventions have significant and meaningful impacts on reducing workers' unsafe behaviors and decreasing the incident rate across the three conditions with the except the frequency of management feedback in the low site risk condition. The strictness of management feedback is directly related to workers' perception of the management norm because managers will not ignore the small risk and give more feedback on workers' unsafe behaviors if the management has stricter risk acceptance. More frequent feedback from managers can lead workers' perception of management norm to be more aligned with actual managers' risk acceptance because workers have more chances to become aware of managers' risk acceptance (Neal et al. 2000). Also, the stimulation of workers' social identification with their project makes their risk acceptance more aligned with the perceived management norm rather than workgroup norm because organizational identification leads to internalizing organizational norms and practices (Dutton et al. 1994). It should be noted that project identity seems to have greater impacts on the incident rate because the project identity has a broader range than the strictness and frequency of management feedback in the parameter sweep.

The experiment results provide construction practitioners insights on how to develop effective safety management interventions in different site conditions. All the three interventions have stable impacts on the incident rate in the modest-risk site condition. Of the three interventions, frequency of the management feedback is proved to be the least effective at reducing workers' unsafe behaviors and improving the incident rate. Therefore, more frequent feedback should be an ancillary intervention to improve workers' safety behaviors in the modest-risk condition. The significant effects of interactions between project identity and other interventions in Figure 5.8 (b) and (c) implies that the project identity has a great potential to create synergies with other interventions. Also, the project identity has more rooms for improvement than the strictness because managers in construction already have somewhat strict risk acceptance and workers' project identification is relatively weak. As such, promoting workers' social identification with their project should be given priority to reduce workers' unsafe behaviors and improve the incident rate in the moderate-risk site. Workers' with stronger project identification would more internalize the project goals and adhere to the management norm. As such, it is expected that promoting workers' project identification could have impacts beyond safety behaviors and spill over into other behaviors such as turnover and productivity in the construction projects.

In the high-risk site condition, effects of the strictness become limited in very strict management feedback as shown in Figure 5.10 (a) and (b). This is because workers in this situation are more likely to be exposed to high-risk work condition, and the medium strictness of managers' risk acceptance is enough to cover the risk. In other words, workers can receive enough feedback from managers to perceive a strict management norm even if managers do not have very strict risk acceptance in this condition. As such, other interventions are recommended to implement after achieving the medium strictness of management feedback in the high-risk site condition. Considering the significant interaction between the strictness and protect identity in Figure 5.10 (b), promoting workers' social identification would be better than increasing the frequency of management feedback.

In the low-risk site condition, it seems to be very difficult to reduce workers' unsafe behaviors and improve the incident rate. This is because workers in this situation are less likely to be exposed to the unsafe condition, also because most potential unsafe conditions remain at a low level of risk. Therefore, workers are rarely exposed to the unsafe work condition that is not acceptable to the management. In this regard, construction practitioners should first have a very strict risk acceptance in the low-risk site condition. Although project identity seems to have a stable influence on the incident rate in Figure 5.11 (c) and Figure 5.12 (c), the effects are limited in the low and medium level of strictness as shown in Figure 5.12 (b). As such, combining very strict management risk acceptance and promoting workers' project identification would be an effective strategy to reduce workers' unsafe behaviors and ultimately reduce the number of incidents in the low site risk condition. It should be noted that cohesiveness of the risk acceptance across the managers in the same project is equally important as the average strictness of managers' risk acceptance. If one manager shows significantly lenient risk acceptance despite a very strict risk acceptance of all other managers in the project, workers' perception of management norm could be influenced by the manager's lenient risk acceptance.

The model and experiments presented in this chapter are not without limitations that can be addressed in future studies. While the model achieves the target performance level (i.e., Level 2) in simulating the socio-cognitive process of construction workers' safety behavior, this does not imply that the model could not be further improved. The model assumes that the site risk does not change during the simulation even if workers are exposed to the different severities of the actual risk based on the beta distribution generated by the static value of site risk. While this assumption is plausible for reproducing macro-level behavioral pattern (i.e., Level 1 and Level 2), more detailed assumptions will be required to achieve micro-level reproduction (i.e. Level 3). Since different trades in construction projects has its own characteristics, the risk of different trades may not be the same. For example, the risk of ironworkers, who frequently work on beams, should be different from that of floor workers who are rarely exposed to the unsafe conditions. Choe and Leite (2016) proposed a safety risk quantification model and compared relative safety risk indices of different trades in construction sites. The future research will be able to establish more detailed assumptions that can reflect changes in the site risk according to the project progress by integrating the project schedule and findings from Choe and Leite (2016) and ultimately achieve the Level 3 performance.

5.7 CONCULSIONS

In this chapter, a novel empirically grounded agent-based model has been constructed to simulate construction workers' safety behaviors and examine the effectiveness of safety management interventions in different site conditions. The theoretical and empirical findings of the socio-cognitive processes of workers' safety behaviors are incorporated in the model. The model is found to accurately represent macro-level of behavioral patterns in previous studies. By running the simulation on the model with different setting for parameters of management interventions and site conditions, it has been demonstrated that all the three interventions generate marked decrease in the incident rate. Also, interaction effects of the interventions in different site risk conditions are found using the parameter sweeping. The results indicate that: (1) promoting workers' project identification would be the most effective strategy in the modest-risk site condition even if all the three interventions have stable impacts on decreasing the incident rate; (2) other interventions should be combined after achieving the medium strictness of the management feedback in the high-risk site condition; and (3) other interventions would not be effective without very strict management feedback in the low-risk site condition. This chapter contributes to the body-of knowledge on construction safety by extending our understanding of construction workers' socio-cognitive process of safety behavior and its interaction with the environment. The findings from the experiments will lay a strong foundation for developing effective safety management interventions in the construction projects.

CHAPTER 6

POTENTIAL OF PHYSIOLOGICAL SENSORY DATA TO UNDERSTAND CONSTRUCTION WORKERS' PERCEIVED RISK

6.1 INTRODUCTION

Risk perception is very important in the safety decision-making process because it directly interacts with risk at workplace. As such, risk perception has consistently been found to be associated with safety behaviors (Chen et al. 2016; Wang et al. 2017). According to the theory of risk homeostasis, the perceived risk is behaviorally compensated if it exceeds an internal threshold (i.e., risk acceptance). In other words, workers could perform unsafe behaviors if the perceived risk is lower than internal risk acceptance. Traditionally, risk perception has been understood as a process of analysis. In this approach, perceived risk has been defined as an individual's subjective assessment of severity and likelihood of an accident that the risk can induce (Hallowell 2010). Based on this approach, researchers have conducted surveys and interviews to measure construction workers' perceived risk in construction projects. Although these survey-based measures have greatly contributed to extending our understanding of workers' perceived risk, they have several notable limitations. First, these post hoc methods are not capable of showing dynamic changes in perceived risk during ongoing work. Considering dynamic and complex changes in work conditions in construction projects, continuous measurement is particularly meaningful in construction. Also, asking workers to participate in survey could be cumbersome and interfere their ongoing tasks. Finally, survey may not be free from the self-reported bias which is inherent in the subjective scale.

On the other hand, researchers have recently understood risk as feelings (Peters et al. 2006). Risk as feeling refers to "individuals' instinctive and intuitive reactions to danger" (Slovic and

Peters 2006). These affective reactions to external stimuli are the results of feedback from the autonomic and somatic nervous system (Epstein 1994) which is separate from the analytic processing system (Kahneman and Frederick 2002). Also, the affective response has been used as a predominant method by which individuals evaluate risk (Slovic et al. 2004; Slovic and Peters 2006). In this sense, risk as analysis is more related to logical, deliberate, and slow risk decision-making process (e.g., financial risk analysis) whereas risk as feeling is closer to autonomic and immediate responses that involves little or no conscious attention (Kinnear et al. 2013). Considering that workers' risk perception is an immediate response to hazard during the work, risk as feeling would be related to risk perception in the safety decision-making process.

Individuals' physiological responses such as heart rate (HR), electrodermal activity (EDA), and skin temperature (ST) possess a great potential to understand risk as feeling. When people perceive significant risk, the sympathetic system of the autonomic nervous system becomes aroused, which results in substantial changes in physiological responses. EDA is an especially useful index of sympathetic arousal because the EDA is the only physiological response that is not contaminated by parasympathetic activity among diverse autonomic physiological variables (Braithwaite et al. 2013). EDA refers to electrical properties of the skin in response to sweat gland activity (Benedek and Kaernbach 2010). The sweat glands are exclusively innervated by the sympathetic nervous system (Kappeler-Setz et al. 2013). If the sympathetic branch of the autonomic nervous system is activated by significant risk, the number of active sweat gland activity increases, which in turn increases EDA. In this sense, EDA has been frequently used to understand individuals' risk perception in the experimental settings (Wang et al. 2002; Kinnear et al. 2013; Schmidt-Daffy 2013; Herrero-Fernández et al. 2016).

Recent advancements in wearable technology have opened a new door toward understanding risk as feeling in construction projects and overcoming the limitations of survey-based methods. Wearable sensors have allowed us to continuously collect workers' physiological responses with minimal interruption of their ongoing works (Jebelli et al. 2018). The physiological sensory data collected from wearable sensors can be used to understand workers' perceived risk during their ongoing task. Despite the potential of EDA and advances in wearable sensing technologies, the feasibility of using EDA to understand construction workers' perceived risk has not been well studied. Although few studies have attempted to use physiological sensory data collected from wearable devices, previous studies have focused on understanding physical aspects of construction project such as workload (Lee and Migliaccio 2016; Hwang and Lee 2017; Lee et al. 2017) and physical fatigue (Aryal et al. 2017). There is a notable paucity of research addressing workers' risk perception in construction sites. With this background, this chapter investigates the feasibility of using EDA that is collected from wearable devices (i.e., off-the-shelf wristband-type wearable sensor) to understand workers' perceived risk during their ongoing work. Specifically, this chapter investigates the distinguishing power of EDA in detecting workers' perceived risk during their ongoing work.

6.2 METHODS

6.2.1 Subjects

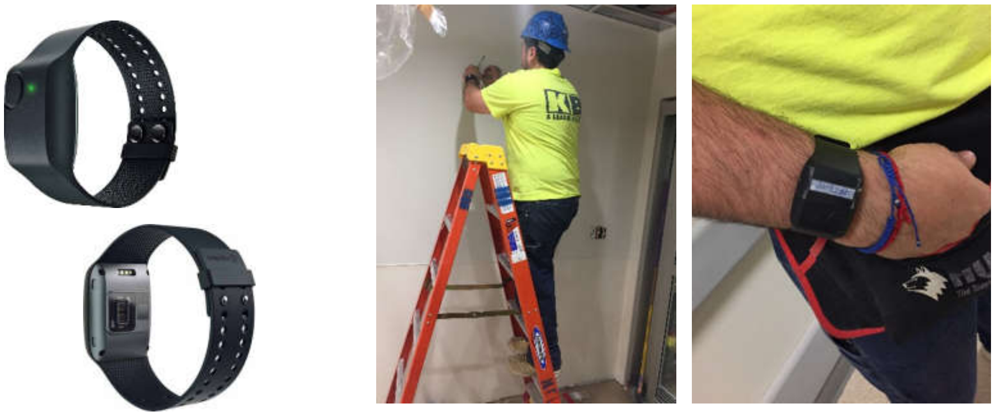
A field data collection was designed to collect workers' EDA during their ongoing tasks. The data collection protocol was approved by the institutional review board at the University of Michigan. In this study, EDA data were collected from seven on-site construction workers (two carpenters, one floorer, and four electricians) and one on-site foremen (electrician foremen). Each worker participated in the data collection during a half of working day either morning (five workers) or afternoon (three workers). The subjects were working at a hospital retrofit project located in Gary, Indiana. The data were collected from February 21, 2017 to February 22, 2017. All participants were male, age between 20 and 50 years (M = 32.37, SD = 8.57), and had three to twenty-eight years of work experience (M = 10.25, SD = 6.72) in the construction industry. All subjects reported no clinical conditions that could affect their physical and mental ability to execute their daily tasks. Table 6.1 describes general information of subjects and duration of the collected data.

Table 6.1 Description of Subject Information and Collected Data

Subject Index	Age	Height (ft)	Weight (lb)	Working Experience (years)	Trade	Data Amount (hours)	Session
S1	33	6’ 2’’	205	10	Electrician	3.82	Morning
S2	20	5’ 7’’	170	3	Floorer	3.78	Morning
S3	50	6’ 1’’	218	25	Carpenter	2.59	Afternoon
S4	31	6’ 0’’	195	11	Electrician foremen	2.61	Afternoon
S5	38	6’ 2’’	180	12	Carpenter	4.68	Morning
S6	27	6’ 0’’	220	5	Electrician	4.68	Morning
S7	35	6’ 0’’	240	13	Electrician	4.56	Morning
S8	25	5’5’’	145	3	Electrician	2.22	Afternoon

6.2.2 Data Collection Procedure

Before the data collection, all subjects were provided and signed an informed consent form that explains the confidentiality of collected data and participants’ rights. Once the consent was received, all subjects were asked to provide their demographic information including age, gender, body-size (i.e., height, weight, and waist size), trade, and work experience. In order to exclude unhealthy subjects, potential participants were also asked whether they have any experience of health problems (e.g., cardiovascular disease): no subjects reported any history of these problems. As shown in Figure 6.1, all subjects were asked to wear an off-the-shelf wristband typed sensor to collect their EDA. Before wearing the sensor, each subject’s skin in the sensor area was cleaned to eliminate any dirt that could potentially obstruct the sensor’s electrode. Then, we checked if the sensor was properly located and asked subjects if all sensors were fitted properly. The wristband sensor records subjects’ EDA with a sampling rate of 4Hz. The wristband sensor is programmed to store the data into its internal storage and to upload the data to the online server in the real time. With the EDA data, the sensor used in this study also provides information of heart rate which can be used to infer subjects’ physical demands. Subjects’ were asked to perform their daily tasks at their usual work area during a half of their working hours. Except for the time for preparing data collection, data collection duration for each subject range from 2.22 to 4.68 hours (Table 6.1). In addition, all subjects’ activities were recorded using a hand-held video camera: that allows for further analysis regarding the relationship between EDA and perceived risk.



EDA Sensor   Subjects Wearing Sensor

Figure 6.1 EDA Data Collection

6.3 DATA ANALYSIS

6.3.1 Artifacts Removal

Physiological signals, even in an experimental setting, include a large number of artifacts. An artifact is defined as “any undesired variation in the measured signal due to sources external to the parameter of interest” (Sweeney et al. 2012). If these artifacts remain in the signal, the signal can be easily misinterpreted and skew the analysis (Sweeney et al. 2012; Hwang et al. 2018). Physiological signals collected in construction sites may include an even larger number of artifacts because of extreme work conditions at construction sites and workers’ excessive body movements (Jebelli et al. 2018). An EDA sensor consists of two electrodes and measures the EDA by passing a minuscule amount of current between the two electrodes in contact with the skin (Boucsein 2012). Therefore, measurement of EDA could be vulnerable to several types of noises such as electrodes popping, excessive movement, and adjustment of sensors (Taylor et al. 2015). To remove artifacts recorded in the signal, a second-order high-pass filter (Hamming window, cut-off frequency f_c = 0.05Hz) was applied to smooth the EDA signals (Braithwaite et al. 2013). While a low-pass filter is widely used to remove the most common artifacts (i.e., environmental artifacts, sensor motion artifacts, muscle movement artifacts) recorded in physiological signals, it is limited to remove large magnitude artifacts related to excessive pressure on electrodes and excessive body movements (Taylor et al. 2015). To eliminate these type of artifacts, a rolling filter of four data points (i.e., the number of data points per second) per block was applied to smooth the EDA signals further. Rolling filter showed a high performance to eliminate most common signal artifacts from electrodermal signals (Jovanovic et al. 2009). The EDA signals before and after applying the filters are represented in Figure 6.2 for one subject (S1) as an example.

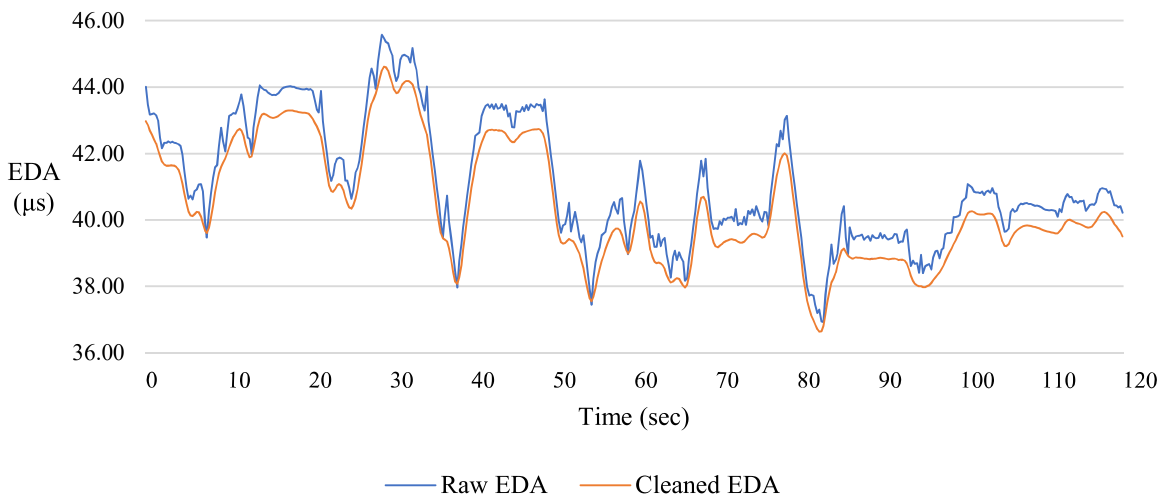


Figure 6.2 Example of Artifacts Removal (S1)

6.3.2 EDA Decomposition

The time series of EDA can be categorized into two components: tonic (i.e., electrodermal level - EDL) and phasic components (i.e., electrodermal response - EDR) that have different time scales and relationships to external stimuli (Boucsein 2012). The EDL denotes slow drifts of the baseline EDA and spontaneous fluctuation in EDA (Greco et al. 2016). The EDL is thought to reflect general changes in sympathetic arousal and can vary substantially across individuals (Kappeler-Setz et al. 2013; Braithwaite et al. 2013). The EDR refers to rapid changing element of the EDA and reflects short-time response to external stimuli (Benedek and Kaernbach 2010; Greco et al. 2016). Typically, EDR shows "a steep incline to the peak and a slow decline to the baseline" patterns (Benedek and Kaernbach 2010). Both components are important and rely on different neural mechanisms (Dawson et al., 2007; Nagai et al., 2004). For example, the EDL has been regarded as a suitable measure of sympathetic activity induced by long-term stress (Pho et al. 2010). On the other hand, EDRs are evoked by attention-grabbing stimuli (e.g., hazard during the work) and attention demanding task (Vaezmousavi et al. 2007; Pho et al. 2010). A convex-optimization-based EDA model (cvxEDA) developed by Gerco et al. (2016) is applied to decompose EDA in this study. The cvxEDA describes EDA as the sum of the tonic component (i.e., EDL), phasic component (i.e., EDR), and additive white Gaussian noise term. Before conducting decomposition, each subject's EDA is normalized using z-score to consider individual variations. Figure 6.3 illustrates an example of decomposition of EDA using cvxEDA for one subject (S4).

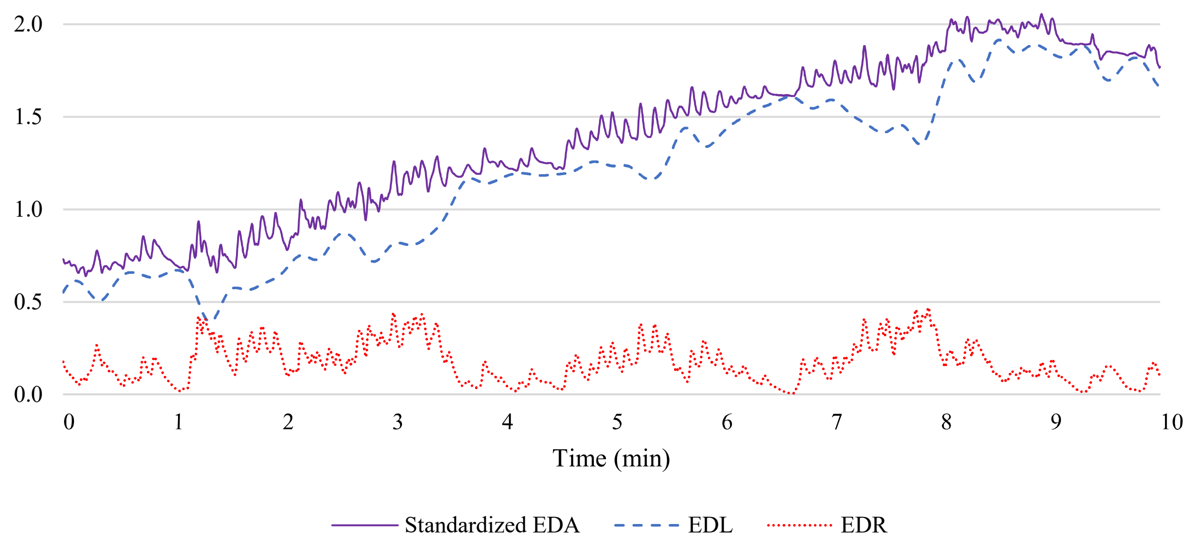


Figure 6.3 Example of cvxEDA Decomposition (S4)

6.3.3 Activity Labeling and Downsampling

The objective of this chapter is to examine the potential of EDA collected from wearable devices to distinguish workers' high-risk perception and low-risk perception during their ongoing work. To do this, all subjects' activities during the data collection were categorized into high-risk activities and low-risk activities using the recorded video. The categorization was completed by two individuals including me who have construction field experience and are familiar with safe and unsafe behaviors in construction projects. The two individuals labeled the subjects' activities every second using their experience and expertise (i.e., frequency = 1Hz). If the labeling results were not consistent between the two observers, the activities were excluded in the analysis. High-risk activities included working on the ladder, working in the ceiling, working with dangerous tools, etc. (a in Figure 6.4). On the other hand, low-risk activities included working on the ground, walking around, talking with coworkers, etc. (b in Figure 6.4).

(a) High Risk Activities (b) Low Risk Activities

Figure 6.4 Examples of Activity Labeling

6.4 RESULTS & DISCUSSION

Long-term assessment of EDA revealed patterns in the participants' sympathetic modulation over the data collection. Figure 6.5 describes variations in EDA for all participants of the morning session. The EDA increases as the data collection progresses at the beginning of the data collection. After that, EDA shows various patterns based on the workers' activities. However, there are notable basins between 09:00 and 09:30 for all the subjects except for S6. This is probably due to the rest time during the morning session. All the participants took a rest at that time, which decreases the general sympathetic arousal and subsequently results in the decrease of the EDA. In the case of S6, EDA starts to decrease from 08:30. This is probably because S6 went to the site office and discussed the drawing with a project engineer at that time. In other words, S6 experienced neither excessive physical activities nor significant risk from 08:30 to 09:00. Also, Figure 6.6 shows changes in EDA for all participants of the afternoon session. Similar to the patterns in the morning session, increases in EDA is found at the beginning of the data collection. After the rise, the signal shows variations based on each subject's activities. S3 and S4 show gradual decreases in the signal from around 13:45 and S8 shows an additional peak around 14:15. This could be explained their activity patterns. S3 and S4 subjects completed their primary task of the day around 13:45 and performed some activities for preparing the next day (e.g., clean the site and paperwork). On the other hand, S8 continuously perform his task until 14:30 at the site and wrap up the daily task after 14:30.

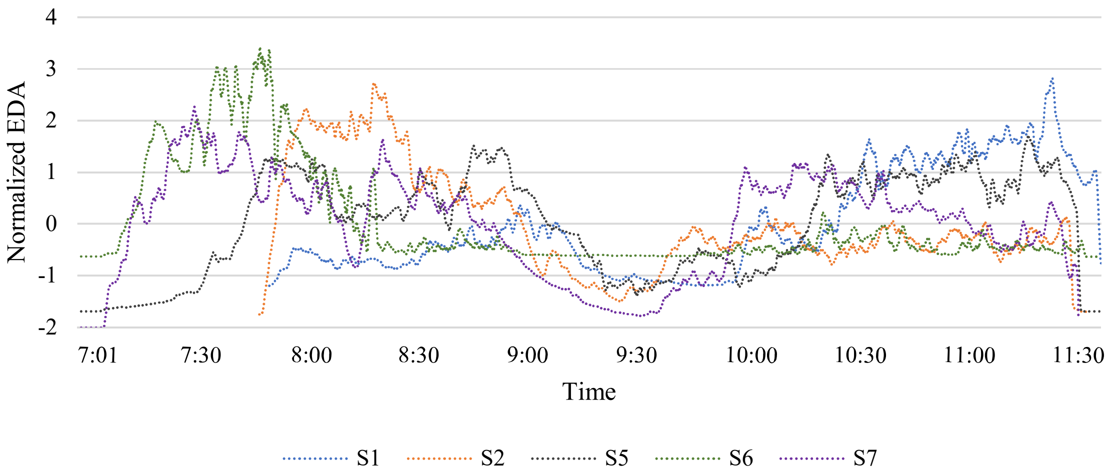


Figure 6.5 Changes in Each Subject's Normalized EDA (Morning Session)

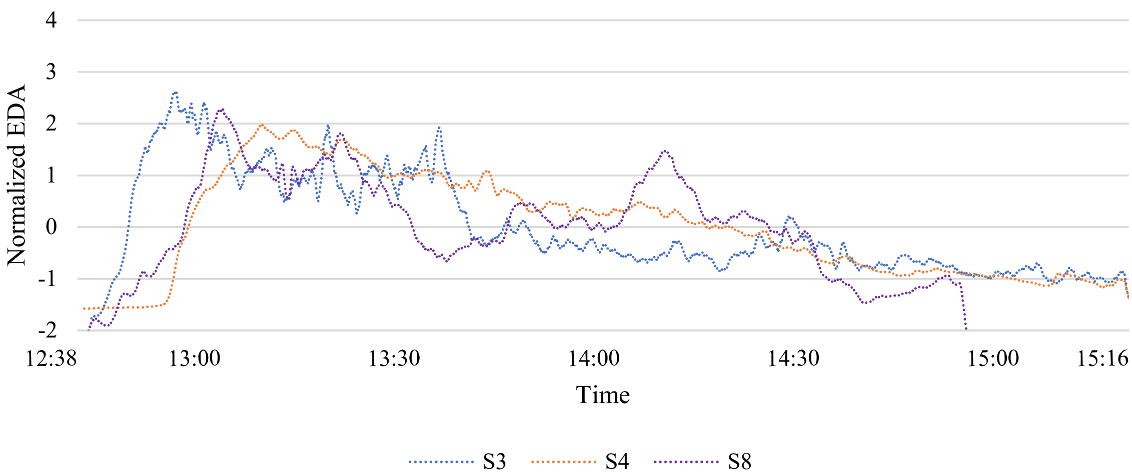


Figure 6.6 Changes in Each Subject's Normalized EDA (Afternoon Session)

Table 6.2 represents the descriptive statistics of each subject’s EDR and EDL in low-risk activities and high-risk activities. As shown in Table 6.2, the mean of each subject’s EDR range from .047 to .877 in low-risk activities and .197 to .889 in high-risk activities. While five subjects (i.e., S2, S4, S5, S6, and S7) show significant mean differences in EDR between low and high-risk activities, other three subjects (i.e., S1, S3, and S8) show insignificant mean differences. Also, the mean of all the subjects' EDR is .401 in low-risk activities and .581 in high-risk activities. Because of the small sample size, which makes it difficult to satisfy the assumptions required for the parametric test (e.g., normality assumption), the Wilcoxon singled-rank test is used to examine the differences. The result indicates that EDR in high-risk activities is statistically higher than low-risk activities (z = 2.100, p = .039). On the other hand, the mean of each subject's EDL range from -.782 to .027 in low-risk activities and from -.971 to .152 in high-risk activities. While four subjects (i.e., S4, S6, S7, and S8) show positive significant mean differences between low and high-risk activities, two subjects (i.e., S3 and S5) show negative significant mean differences. Other two subject (i.e., S1 and S2) do not show significant differences in EDL between low and high-risk activities. The result of the Wilcoxon single-ranked test shows that there is no significant difference in EDL between high and low-risk activities (z = 1.12, p = .312). Moreover, Figure 6.7 represents the distribution of all subjects' EDR and EDL in low and high-risk activities. The graphs show consistent results from the results of the Wilcoxon single-ranked test on the differences in EDL and EDR between low and high-risk activities.

Table 6.2 Each Subject's Descriptive Statistics (EDR and EDL)

Subject	EDR					EDL				
	Low Risk		High Risk		Mean Difference	Low Risk		High Risk		Mean Difference
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
S1	.303	.158	.312	.182	.009	-.171	.697	-.126	.654	.044
S2	.640	.275	.889	.558	.248	-.654	.709	-.545	.873	.019
S3	.877	.425	.837	.354	-.040	-.782	.676	-.971	.556	-.189
S4	.047	.074	.197	.187	.150	-.721	.376	.088	.273	.809
S5	.336	.296	.626	.328	.290	-.236	.886	-.545	.780	-.309
S6	.377	.434	.859	.523	.482	-.398	.768	-.174	1.103	.224
S7	.291	.257	.586	.286	.295	.027	.456	.152	.550	.125
S8	.338	.231	.340	.195	.002	-.212	.665	.104	.486	.315
Mean	.401	.234	.581	.254	.180	-.382	.276	-.252	.373	.130

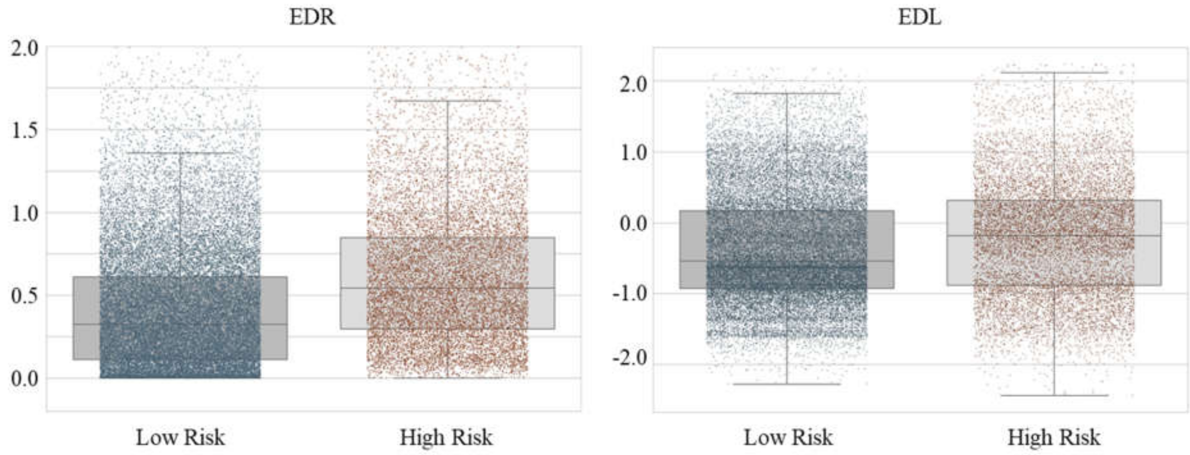


Figure 6.7 Distribution of All Subjects' EDR and EDL in Low & High Risk Activities

To examine the effects of high-risk activities on workers' EDR during their ongoing work, a Hierarchical Linear Modeling (HLM) was performed. The term HLM is used interchangeably with Multi-Level Model (MLM) and is used to analyze data with hierarchical structure (Snijders 2014). Since this study collected data multiple times from each subject, the data involves a hierarchical structure (Level 1 – each data, Level 2 – each subject). Also, as shown in Table 6.2, the mean of each subject's EDR are different from each other. Moreover, there are variations in the differences in EDR between low and high-risk activities across the subjects as shown in Figure 6.8. For these reason, HLM with the two levels (i.e., Level 1 – each data, Level 2 – each subject) is conducted using the SPSS Mixed Procedure (Heck et al. 2013) in order to examine the effect of high-risk activities. In the model, high-risk activity is included using dummy variable (i.e., 0: low-risk activity, 1: high-risk activity). Also, %Heart Rate Reserve (%HRR), which is an index of individuals' physical demands (Hwang and Lee 2017), is included as a control variable because EDA could be affected by physical activities (Poh et al. 2010). EDL is also included as a control variable because EDR and EDL are estimated from the same source (i.e., EDA). Since the duration of the data collect is not the same across subjects (Table 6.2), the number of data for each subject is not the same in this study. As a consequence, this disproportionate number of data can lead to the misinterpretation of the results because impacts of each subject are affected by the number of data that the subject has. In other words, a subject with a large number of data can have a greater impact on the results and vice versa. To prevent this problem, the equal number of data for each subject (i.e., one-minute data for high-risk activity and one-minute data for low-risk activity) were randomly sampled before conducting HLM.

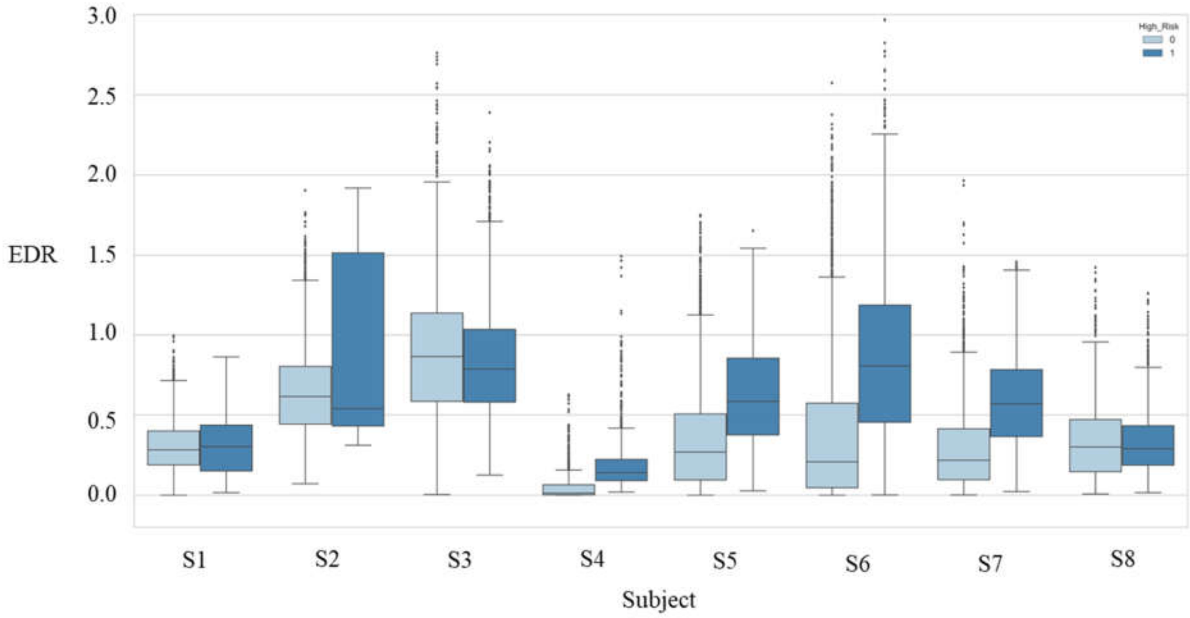


Figure 6.8 Distribution of Each Subject's EDR in Low Risk Activities and High Risk Activities

The results of HLM are represented in Table 6.3. First, the unconditional model that could be described by the following equation: $EDR_{ij} = \beta_0 + u_j + e_{ij}$ is used for testing the effect of the subject on EDR. In this equation, u_j represents the level 2 (i.e., subject) residuals that refer to the differences between subject j's mean and the overall mean. The level 1 (i.e., data) residual e_{ij} represents the differences between the value of data and the mean of subject j. The variance partition coefficient (VPC) is .048/(.118 + .048) = .41, which indicates that 41% of the variance in EDR can be attributed by differences between subjects. Then, a random intercept model (Model 1) which can be described by the following equation: $EDR_{ij} = \beta_0 + \beta_1 High\_Risk_{ij} + u_j + e_{ij}$ is tested. In the model, the overall relationship between EDR and high-risk activities is represented by a linear line with intercept β_0 and slope β_1. The intercept for a given subject j is $\beta_0 + u_j$, but the slope of the line is assumed to be fixed across subjects. In other words, the effect of high-risk activities on EDR is assumed to be the same for all subjects. As shown in Table 3, high-risk activity is a significant predictor of EDR ($\beta_1 = .205$, $t = 9.664$, $p \approx .000$). The result implies that the effect of high-risk activity is to increase the predicted EDR by .205. The VPC in Model 1 is .048/(.108+.048) = .31 that implies that after accounting high-risk activity, 31% of the unexplained variance in EDR is due to differences between subjects. After that, a random slope model (Model 2) that allows the slope to vary across subjects is tested. The random slope model can be represented by the following equation: $EDR_{ij} = \beta_0 + \beta_1 High\_Risk_{ij} + u_{oj} + u_{1j} High\_Risk_{ij} + e_{ij}$. In this model, the slope of the average regression line is β_1, and the slope of the subject j is $\beta_1 + u_{1j}$. The result shows that effects of high-risk activity on EDR is statistically significant (β_1 = .205, t = 3.710, p = .006). The likelihood ratio test statistics (i.e., LR = $-2\log L_1 - (-2\log L_2)$) comparing Model 1 and Model 2 is 619.820 – 587.305 = 32.515 which is compared to a chi-squared distribution on two degrees of freedom. The *p*-value for the test is < .001 which implies that the effect of high-risk activity on EDR varies across subjects. As the last step, the final model that includes all the control variables (i.e., %HRR and EDL) is tested. Since %HRR and EDL is also involved with hierarchical data structure, the model also includes level 2 residuals of them (i.e., u_{2j} for %HRR and u_{3j} for EDL). As shown in Table 6.3, high-risk activity has significant effects on EDR (β_1 = .195, t = 4.058, p = .004). Specifically, the value of regression coefficient implies that high-risk activity is associated with .195 increase in EDR compared with low-risk activity. However, the result shows that %HRR (β_2 = .164, t =.628, p = .547) and EDL (β_3 = .072, t = 1.700, p = .133) are not significant predictors. Also, the likelihood ratio test statistics comparing Model 2 and Model 3 is 587.305 – 399.446 = 187.859 on nine degrees of freedom. (p < .001).

Table 6.3 Result of Hierarchical Linear Modeling

$EDR_{ij} = \beta_0 + \beta_1 High\_Risk_{ij} + \beta_2 \%HRR_{ij} + \beta_3 EDL_{ij} + u_{oj} + u_{1j} High\_Risk_{ij} + u_{2j} \%HRR_{ij} + u_{3j} EDL_{ij} + e_{ij}$

Parameters	Unconditional	Model 1 (Random Intercept)	Model 2 (Random) Slope	Model 3 (Final)
Regression coefficient (fixed effects)				
Intercept (β_0)	.480 (.078)**	.378 (.079)**	.378 (.077)**	.384 (.094)**
High Risk(β_1)	-	.205 (.021)**	.205 (.055)**	.195 (.048)**
%HRR (β_2)	-	-		.164 (.261)
EDL ($\beta 3$)	-	-		.072 (.042)
Variance components (random effects)				
Residual (σ_e^2)	.118 (.005)	.108 (.005)	.103 (.005)	.082 (.004)
Intercept (σ_{u0}^2)	.048 (.024)	.048 (.024)	.046 (.024)	.063 (036)
Slope – High Risk (σ_{u1}^2)			.021 (.012)	.015 (.009)
Slope – %HRR (σ_{u2}^2)				.467 (.270)
Slope – EDL (σ_{u3}^2)				.012 (.008)
Subject & High-Risk Covariance (σ_{u01})			-.003 (.012)	.001 (.013)
Subject & %HRR Covariance (σ_{u02})				-.031 (.071)
Subject & EDL Covariance (σ_{u03})				.025 (.015)
High Risk & %HRR Covariance (σ_{u12})				-.033 (.037)
High Risk & EDL Covariance (σ_{u13})				.026 (.006)
%HRR & EDL Covariance (σ_{u23})				-.017 (.031)
Model summary				
-2 Log Likelihood	708.908	619.820	587.305	399.446
Number of estimated parameters	3	4	6	15

Parameter estimate standard errors listed in parentheses
**p < .01

The result of this study presents the potential of physiological sensory data collected from wearable devices to understand workers' perceived risk during their on-going work by showing differences in EDR between low and high-risk activities (Table 6.2) and the relationship between high-risk activity and EDR (Table 6.3). Workers' EDR during high-risk activities was significantly higher than EDR during low-risk activities. However, there were no significant differences in EDL between low and high-risk activities. Also, workers' EDR was significantly influenced by high-risk activity after controlling the effects of physical demands and EDL on EDR as well as variations in individual differences. Considering that EDR is a phasic component of EDA and risk perception is an immediate reaction to detected hazard, EDR would be more related to risk perception than EDL.

Although this study presents the feasibility of physiological responses collected from workers' wearable devices to understand their perceived risk, there is much room for exploring additional potential in the future. In addition to the value of EDR, various features of EDR such as standard deviation of EDR, the linearity of EDR, etc. can deepen our understanding of workers' perceived risk during their ongoing work. The relationships between these various features and workers' perceived risk can be investigated in future studies. Also, other physiological variables such as heart rate variability (HRV), inter-beat interval (IBI) and skin temperature (ST) are worthwhile to study in the future. For example, a sympathetic nervous system aroused by significant risk innervates the heart which results in changes in physiological responses that are related to heart activity such as HRV, IBI, etc. (Doorley et al. 2015). This study has focused on EDA because these other physiological variables can be contaminated by parasympathetic nervous system activity. In the future, more advanced data analysis method can be applied for using these physiological responses to understand sympathetic arousal caused by risk in construction sites.

Physiological responses collected from wearable devices are expected to deepen our understanding of risk perception during workers' ongoing work. Since wearable devices measure an individual's physiological response to hazard during the work, it would be more related to one's own perceived risk. This personalized measurement could offer a strong foundation to explore new areas for risk perception studies. For example, we can investigate effects of individual factors (e.g., work experience, accident experience, trade, etc.) on workers' risk perception by comparing the physiological responses in the same condition. Also, continuous measurement of workers' physiological responses to improve our understanding of risk perception provides ample opportunities to improve construction safety management. Specifically, the integration of physiological responses and other contextual information has a great potential to improve construction safety management practice. For example, we will be able to find hazardous areas in a construction project by integrating workers' perceived risk as estimated from physiological responses and their location that can be identified using GPS or indoor GPS embedded in wearable devices. Based on the hazardous areas, safety managers will be able to recognize places where he/she needs to pay more attention to prevent accidents. Also, the perceived risk estimated from physiological responses can be integrated with other information such as activity, workgroup, schedule, etc. that can be extracted from building information model (BIM) in order to improve safety in construction sites. For example, activity information from BIM could be useful to understand the causes of the perceived risk from wearable devices. Safety managers will be able to identify the causes of perceived risk based on the characteristics of activities at the hazardous area.

6.5 CONCLUSION

This chapter investigates the potential of using physiological sensory data (i.e., EDA) collected from off-the-shelf wristband typed sensors to understand construction workers' perceived risk during their ongoing work. A field data collection has been conducted to examine the potential. The results indicate that: (1) there are significant differences in EDR between low and high-risk activities; (2) high-risk activity significantly affect workers' EDR during their ongoing work. The main contribution of this chapter is to show the feasibility of using wearable devices to understand workers' perceived risk in construction sites continuously. The findings from this chapter will lay a strong foundation for improving safety management in construction sites. Considering the complexity and dynamicity of workers' task at the workplace, continuously monitoring of workers' physiological response is expected to contribute to a more in-depth understanding of workers' perceived risk in construction sites.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 SUMMARY OF RESEARCH

This research effort began with the following overarching research goals: (1) to improve our understanding of the role of different safety norms and social identities in workers' safety behaviors; (2) to enhance our understanding of how workers' safety decision-making processes and their interaction with the environments (i.e., coworkers, managers, risk conditions, safety management practices) affect workers' safety behaviors; and (3) to explore advanced methods to deepen our understanding of the interaction between safety decision-making processes and risk during work. Considering these goals, the research had these five more specific research objectives: (1) to identify the current status of safety norms and social identities at construction sites, (2) to explore the effect of different safety norms and social identities on workers' safety behaviors, (3) to identify the impact of different cultural backgrounds and organizational structure on social influence process, (4) to create a formal behavioral model for safety behaviors in order to explore the mechanism behind the link between social influence, decision-making process, and safety behaviors, and (5) to examine the potential of advanced technologies (i.e., wearable devices) for continuously monitoring of workers' perceived risk.

To achieve these research objectives, four inter-related studies were conducted. A summary of these studies' results and implications are as follows.

1. The Current Status of Safety Norms and Social Identities at Construction sites: This study conducted behavioral economic experiments (i.e., norm elicitation protocol) to compare safety norms shared by workers as opposed to safety norms shared by managers. Also, I conducted surveys to measure construction workers' social identification with multiple groups in their projects (i.e., workgroup, company, project, union, and trade). This study revealed that safety norms shared by workers are significantly lenient than safety norms shared by managers. Also, project identity was the least salient identity to construction workers' self-concept even if the project is the only common organizational background among project participants. It is also found that workers' personal standard regarding safety behaviors are associated with their perceived group norms.

2. Influence of Safety Norms and Social Identities on Workers' Safety Behaviors: This study investigated the role of different safety norms (i.e., perceived workgroup norm and perceived management norm) and social identities (i.e., project identity and workgroup identity) in workers' safety behaviors. It was found that perceived workgroup norm partially mediates the relationship between perceived management norm and safety behaviors. More importantly, workers' social identification with their project positively moderates the relationship between perceived management norm and safety behaviors and negatively moderates the relationship between perceived workgroup norm and safety behaviors. In other words, project identification intensifies the positive influence of perceived management norms and attenuates the negative influence of perceived workgroup norm on workers' safety behaviors. This finding shows the role of workers' project identification in promoting positive social influence to improve their safety behaviors in construction projects.

3. Influence of Cultural Backgrounds and Organizational Structure on Social Influence Process: This study examines and compares the role of different safety norms and project identity in construction workers' safety behaviors in the U.S., Korea, and Saudi Arabia. It was found that workers' social identification with their projects moderates the relationship between social norms (e.g., perceived management norms and perceived workgroup norms) and safety behavior in the U.S. and Korea. Also, the individualistic culture in the U.S. may lead to a direct effect of personal attitudes, and the collectivistic culture in Korea can bring about the direct effects of perceived management norms and perceived workgroup norms on safety behavior. On the other hand, in Saudi Arabia, although workers already have a salient project identity due to the direct hiring system, interactions between project identity and social norms are not significant predictors of safety behavior because perceived management norms may not be strict enough to elicit behavioral changes in improving safety behavior.

4. An Empirically Based Agent-Based Model of the Socio-Cognitive Process of Construction Workers' Safety Behavior: In this study, I created a formal behavioral model that integrates workers' safety decision-making processes and social influence. In this model, construction workers determine safety behaviors by comparing perceived risk and their risk acceptance. The theoretical and empirical findings of the socio-cognitive processes of workers' safety behaviors are incorporated to determine perceived risk and risk acceptance in the model. The model is found to represent macro-level of behavioral patterns in previous studies accurately. The results of simulation experiments provide meaningful insights into safety management strategies. The results indicate that: (1) promoting workers' project identification would be the most effective strategy in the modest-risk site condition; (2) other interventions should be combined after achieving the medium strictness of the management feedback in the high-risk site condition; and (3) other interventions would not be effective without very strict management feedback in the low-risk site condition.

5. Potential of Using Physiological Sensory Data Collected from Wearable Device to Understand Workers' Perceived Risk: This study examined the potential of physiological sensory data collected from off-the-shelf wristband type sensors to understand workers' perceived risk during their ongoing work. The results from field data collection revealed that there were significant differences in workers' EDR between low and high-risk activities. Also, HLM indicated that high-risk activity is significantly associated with workers' EDR after controlling the effects of physical demands and EDL on EDR. This suggests that EDR collected from wristband has a potential to distinguish workers' high-risk perception and low-risk perception during their ongoing work.

7.2 FUTURE RESEARCH

While this work has expanded our understanding of construction workers' safety behaviors and the role of socio-cognitive process in determining safety behaviors, many questions remain which still warrant further attention in future research efforts. A few such questions follow.

1. What are the role of different leaders in construction projects (e.g., foremen, safety manager, project manager) in shaping workers' perceived management norms? How, and to what extent, does each leader affect workers' perceived management norms?

2. How do we incorporate workers' project identification into the socio-cognitive processes in safety behaviors? How do we elaborate the formal behavioral model of this study to integrate the project identification processes?

3. What would be considered feasible managerial actions that can effectively promote workers' social identification with their project? What are the mechanisms of workers' project identification? How, and to what extent, do individuals' attributes (e.g., personal attitude) affect their project identification? What are the impacts of the characteristics of project and interaction with managers (e.g., leadership style, communication climate) on workers' project identification?

4. How does government policy on safety affect social influence on construction workers' safety behaviors? How does government policy interact with cultural backgrounds and organizational structures to affect construction workers' safety behaviors?

5. How do we use our ability to measure physiological responses through wearable devices to improve workers' safety and health? How do we integrate different physiological responses to broaden and deepen our understanding of the socio-cognitive mechanism of workers' safety behaviors?

7.3 Final Remark

Due to the temporary nature of construction projects, the socio-cognitive aspect of workers' behaviors in construction projects has been overlooked in academia as well as in practice. However, external formal controls may not enough to successfully manage workers' behaviors in construction projects. This study investigated how to promote workers' willingness to take action that is beneficial for a project (i.e., safety behaviors) using various quantitative methods. While the methodologies and framework focused specifically on workers' safety behaviors in the built environment, these methods are not conceptually constrained to the study of safety behavior. It is expected that findings from this study could have theoretical and managerial applications beyond safety behaviors and spill over into other behaviors such as turnover and productivity in the construction projects. Additional research efforts to investigate the socio-cognitive aspects of diverse behavioral contexts could further enhance human resource management in construction projects.

APPENDICES

APPENDIX A - SURVEY QUESTIONNAIRE 1: CONSTRUCTION WORKER'S SOCIAL IDENTITIES AND THEIR SOCIAL NORMS AND PERSONAL STANDARD REGARDING SAFETY

CONSTRUCTION CREW SURVEY

This study is performed by the University of Michigan. The goal of this survey is to find out the most significant causes of construction workers' daily decisions and behavior. The result of this survey will help improve jobsite conditions and project/company policies for you and your fellow workers.

- Participating in this survey is VOLUNTARY.
- All of your answers on this questionnaire will be CONFIDENTIAL.
- Your answers will be used ONLY FOR RESEARCH PURPOSES

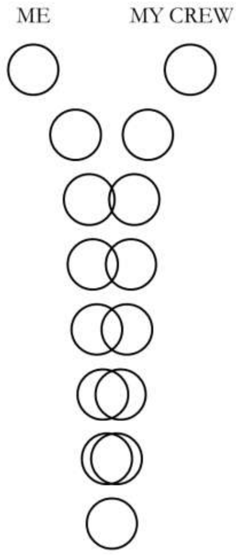
Please proceed to the next page if you agree to participate in this survey.

IRB Study ID: HUM00052356 IRB Amendment ID: AME00045440

SECTION 1.

Take a moment to think about your crew (a crew usually means a group of workers who work with the same foreman).

Imagine that the left circles represent your own identity and the right circles represent your CREW's identity. Please indicate which case (A, B, C, D, E, F, G or H) best describes the level of overlap between your own identity and your CREW's identity.



- A ☐ Far Apart
- B ☐ Close Together but Separate
- C ☐ Very Small Overlap
- D ☐ Small Overlap
- E ☐ Moderate Overlap
- F ☐ Large Overlap
- G ☐ Very Large Overlap
- H ☐ Complete Overlap

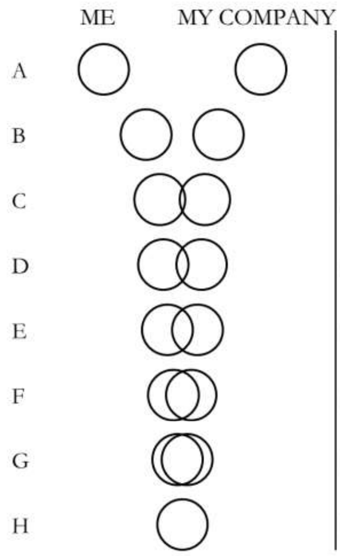
Please circle the answer that best describes your feelings for each statement.

	Statement	Strongly Disagree	Disagree	Somewhat Disagree	Neither agree nor disagree	Somewhat Agree	Agree	Strongly Agree
1	When someone criticizes my crew, it feels like I am criticized.	-3	-2	-1	0	1	2	3
2	When I talk about my crew, I usually say 'we' rather than 'they'.	-3	-2	-1	0	1	2	3
3	I think my foreman is one of us.	-3	-2	-1	0	1	2	3
4	I am attached to my crew.	-3	-2	-1	0	1	2	3
5	I am happy to be a member of my crew.	-3	-2	-1	0	1	2	3
6	I have respect for my crew.	-3	-2	-1	0	1	2	3
7	I am proud to be a member of my crew.	-3	-2	-1	0	1	2	3

IRB Study ID: HUM00052356   IRB Amendment ID: AME00045440

What is your COMPANY?

Imagine that the left circles represent your own identity and the right circles represent your COMPANY's identity. Please indicate which case (A, B, C, D, E, F, G or H) best describes the level of overlap between your own identity and your COMPANY's identity.



- ☐ Far Apart
- ☐ Close Together but Separate
- ☐ Very Small Overlap
- ☐ Small Overlap
- ☐ Moderate Overlap
- ☐ Large Overlap
- ☐ Very Large Overlap
- ☐ Complete Overlap

Please circle the answer that best describes your feelings for each statement.

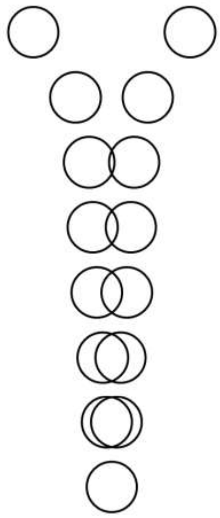
	Statement	Strongly Disagree	Disagree	Somewhat Disagree	Neither agree nor disagree	Somewhat Agree	Agree	Strongly Agree
1	When someone criticizes my company, it feels like I am criticized.	-3	-2	-1	0	1	2	3
2	When I talk about my company, I usually say 'we' rather than 'they'.	-3	-2	-1	0	1	2	3
3	I am attached to my company.	-3	-2	-1	0	1	2	3
4	I am happy to be a member of my company.	-3	-2	-1	0	1	2	3
5	I have respect for my company.	-3	-2	-1	0	1	2	3
6	I am proud to be a member of my company.	-3	-2	-1	0	1	2	3

IRB Study ID: HUM00052356 IRB Amendment ID: AME00045440

What is your PROJECT SITE?

Imagine that the left circles represent your own identity and the right circles represent your PROJECT's identity. Please indicate which case (A, B, C, D, E, F, G or H) best describes the level of overlap between your own identity and your PROJECT's identity.

ME THIS PROJECT



A	☐ Far Apart
B	☐ Close Together but Separate
C	☐ Very Small Overlap
D	☐ Small Overlap
E	☐ Moderate Overlap
F	☐ Large Overlap
G	☐ Very Large Overlap
H	☐ Complete Overlap

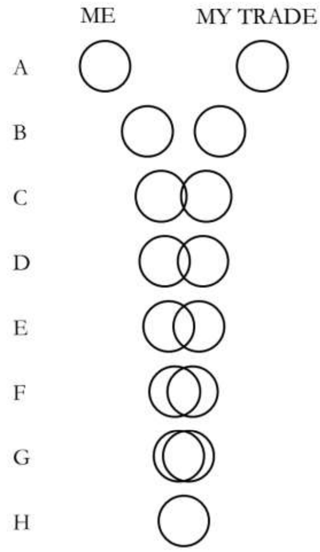
Please circle the answer that best describes your feelings for each statement.

	Statement	Strongly Disagree	Disagree	Somewhat Disagree	Neither agree nor disagree	Somewhat Agree	Agree	Strongly Agree
1	When someone criticizes this project, it feels like I am criticized.	-3	-2	-1	0	1	2	3
2	When I talk about this project, I usually say 'we' rather than 'they'.	-3	-2	-1	0	1	2	3
3	I am attached to this project.	-3	-2	-1	0	1	2	3
4	I am happy to be a member of this project.	-3	-2	-1	0	1	2	3
5	I have respect for this project.	-3	-2	-1	0	1	2	3
6	I am proud to be a member of this project.	-3	-2	-1	0	1	2	3

IRB Study ID: HUM00052356 IRB Amendment ID: AME00045440

What is your TRADE (e.g., carpenter, laborer, plumber,….)?

Imagine that the left circles represent your own identity and the right circles represent your TRADE's identity. Please indicate which case (A, B, C, D, E, F, G or H) best describes the level of overlap between your own identity and your TRADE's identity.



☐ Far Apart
☐ Close Together but Separate
☐ Very Small Overlap
☐ Small Overlap
☐ Moderate Overlap
☐ Large Overlap
☐ Very Large Overlap
☐ Complete Overlap

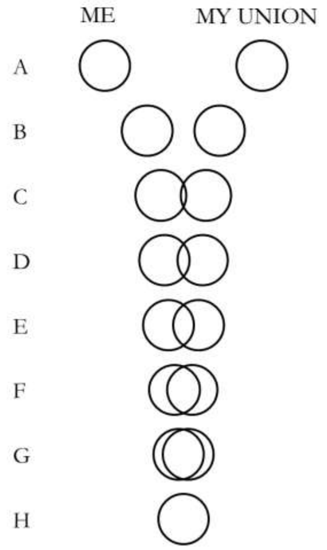
Please circle the answer that best describes your feelings for each statement.

	Statement	Strongly Disagree	Disagree	Somewhat Disagree	Neither agree nor disagree	Somewhat Agree	Agree	Strongly Agree
1	When someone criticizes my trade, it feels like I am criticized.	-3	-2	-1	0	1	2	3
2	When I talk about my trade, I usually say 'we' rather than 'they'.	-3	-2	-1	0	1	2	3
3	I am attached to my trade.	-3	-2	-1	0	1	2	3
4	I am happy to be a member of my trade.	-3	-2	-1	0	1	2	3
5	I have respect for my trade.	-3	-2	-1	0	1	2	3
6	I am proud to be a member of my trade.	-3	-2	-1	0	1	2	3

Are you a union member? If yes, what is your union?

If you are not a union member, skip this page.

Imagine that the left circles represent your own identity and the right circles represent your UNION's identity. Please indicate which case (A, B, C, D, E, F, G or H) best describes the level of overlap between your own identity and your UNION's identity.



- ☐ Far Apart
- ☐ Close Together but Separate
- ☐ Very Small Overlap
- ☐ Small Overlap
- ☐ Moderate Overlap
- ☐ Large Overlap
- ☐ Very Large Overlap
- ☐ Complete Overlap

Please circle the answer that best describes your feelings for each statement.

	Statement	Strongly Disagree	Disagree	Somewhat Disagree	Neither agree nor disagree	Somewhat Agree	Agree	Strongly Agree
1	When someone criticizes my union, it feels like I am criticized.	-3	-2	-1	0	1	2	3
2	When I talk about my union, I usually say 'we' rather than 'they'.	-3	-2	-1	0	1	2	3
3	I am attached to my union.	-3	-2	-1	0	1	2	3
4	I am happy to be a member of my union.	-3	-2	-1	0	1	2	3
5	I have respect for my union.	-3	-2	-1	0	1	2	3
6	I am proud to be a member of my union.	-3	-2	-1	0	1	2	3

SECTION 2.

In this section, you have a chance to win a maximum of $100 monetary reward!

We will randomly select 10% of all respondents in this survey. If you are selected, your responses in this section will be compared with the responses of another respondent among your crew, and you will receive $10 for each of your responses matched with the responses of the target respondent. The maximum of the reward is $100, which means that even if you get more than 10 responses of yours matched with the responses of the target respondent, you will receive $100. If you do not have any response that is matched with the response of the target respondent, you will not receive any incentives. Therefore, the range of incentives that you can receive is $0 - $100. If you are interested in receiving the incentives, please provide your address at the end of the survey so that we can send the incentives to you. The incentives will be mailed in a form of gift certificate. If you do not complete the section 2, you will not be considered for the award.

Please proceed to the next page if you agree to participate in this survey.

IRB Study ID: HUM00052356 IRB Amendment ID: AME00045440

Please imagine that James is a member of your crew, and he has been working with you since your crew started to work at your project site.

Please choose WHAT A TYPICAL MEMBER OF YOUR CREW WOULD THINK if James shows behavior listed below.

	Behavior	Very Inappropriate	Somewhat Inappropriate	Somewhat Appropriate	Very Appropriate
1	James takes absence when he has a hangover, and he informs his absence to his foreman early in the morning.				
2	James does not take absence at all unless he has an emergent situation like severe injury or sickness.				
3	James takes absence without a notice when he does not want to work.				
4	James takes absence when he feels too sick to work well, and he informs his absence to his foreman early in the morning.				
5	James takes absence when he has some personal situation like sickness of a family member, and he informs his absence to his foreman early in the morning.				
6	James takes absence when he does not want to work, and he informs his absence to his foreman early in the morning.				
7	James takes absence when he has minor illness such as colds and headaches, and he informs his absence to his foreman early in the morning				

Please imagine that Robert is another member of your crew. He works at a workspace where a fall protection is required by the OSHA regulation.

Please choose WHAT A TYPICAL MEMBER OF YOUR CREW WOULD THINK if Robert shows behavior listed below.

	Behavior	Very Inappropriate	Somewhat Inappropriate	Somewhat Appropriate	Very Appropriate
1	Robert always connects his snaphooks to an anchor point. If he cannot find an object he can securely connect his snaphooks to, he does not continue to work.				
2	Robert connects his snaphooks to an anchor point only when he perceives a danger of falling.				
3	Robert does not connect his snaphooks to an anchor point even if he works on a dangerous task and the fall protection system does not bother his work.				
4	Robert always connects his snaphooks to an anchor point whenever a fall protection is required. However, he continues to work even if he cannot find an object he can securely connect his snaphooks to.				
5	Robert connects his snaphooks to an anchor point only when he perceives a danger of falling and the fall protection system does not bother his work.				

SECTION 3.

In this section, you are asked to TELL US YOUR PERSONAL OPINION ABOUT THE ACTIONS listed in the section 2.

Please choose WHAT YOU WOULD THINK if James shows behavior listed below.

	Behavior	Very Inappropriate	Somewhat Inappropriate	Somewhat Appropriate	Very Appropriate
1	James takes absence when he has minor illness such as colds and headaches, and he informs his absence to his foreman early in the morning.				
2	James takes absence when he has a hangover, and he informs his absence to his foreman early in the morning.				
3	James takes absence when he does not want to work, and he informs his absence to his foreman early in the morning.				
4	James does not take absence at all unless he has an emergent situation like severe injury or sickness.				
5	James takes absence when he has some personal situation like sickness of a family member, and he informs his absence to his foreman early in the morning.				
6	James takes absence when he feels too sick to work well, and he informs his absence to his foreman early in the morning.				
7	James takes absence without a notice when he does not want to work.				

IRB Study ID: HUM00052356 IRB Amendment ID: AME00045440

Please choose WHAT YOU WOULD THINK if Robert shows behavior listed below.

Behavior	Very Inappropriate	Somewhat Inappropriate	Somewhat Appropriate	Very Appropriate
1 Robert connects his snaphooks to an anchor point only when he perceives a danger of falling.				
2 Robert always connects his snaphooks to an anchor point. If he cannot find an object he can securely connect his snaphooks to, he does not continue to work.				
3 Robert always connects his snaphooks to an anchor point whenever a fall protection is required. However, he continues to work even if he cannot find an object he can securely connect his snaphooks to.				
4 Robert does not connect his snaphooks to an anchor point even if he works on a dangerous task and the fall protection system does not bother his work.				
5 Robert connects his snaphooks to an anchor point only when he perceives a danger of falling and the fall protection system does not bother his work.				

SECTION 4.

NAME (Necessary For Payment)	How long have you been working at this site?	Who is your foreman? (Necessary for crew identification)

ADDRESS (Necessary For Payment)

THANK YOU SO MUCH FOR YOUR PARTICIPATION.

WE APPRECIATE IT.

APPENDIX B – SURVEY QUESTIONNAIRE 2: CONSTRUCTION WORKER'S PERECIVED SAFETY NORMS AND SOCIAL IDENTITIES

CONSTRUCTION CREW SURVEY

This study is performed by the University of Michigan. The objective is to investigate the underlying causes of construction workers' daily decisions and behaviors—specifically, those related to worker safety.

Please respond to each of the questions to the best of your ability. Your honest responses will be highly valuable to our research. The results of this survey will help improve jobsite conditions and policies for you and your fellow workers.

- All of your answers on this questionnaire will be CONFIDENTIAL.
- Participating in this survey is VOLUNTARY.
- Your answers will be used ONLY FOR RESEARCH PURPOSES

Please proceed to the next page if you agree to participate in this survey.

IRB Study ID: HUM00052356 IRB Amendment ID: AME00045440

SECTION 1.

There are a number of rules regulating workers' actions at construction sites for safety reasons. Examples are personal protective equipment, fall protection, eye protection, etc. You will be asked to tell us your thoughts and feelings about those types of rules.

Please circle the word that best fits your thoughts and feelings about safety rules.

Attitudes

1. I feel that safety rules are

Very Unpleasant	Unpleasant	Somewhat Unpleasant	Neither Unpleasant nor Pleasant	Somewhat Pleasant	Pleasant	Very Pleasant
-3	-2	-1	0	1	2	3

2. I think that safety rules are

Very disadvantageous	disadvantageous	Somewhat disadvantageous	Neither disadvantageous nor advantageous	Somewhat advantageous	advantageous	Very advantageous
-3	-2	-1	0	1	2	3

3. I think that safety rules are

Very Useless	Useless	Somewhat Useless	Neither Useless nor Useful	Somewhat Useful	Useful	Very Useful
-3	-2	-1	0	1	2	3

4. I think that safety rules are

Very Unfavorable	Unfavorable	Somewhat Unfavorable	Neither Unfavorable nor Favorable	Somewhat Favorable	Favorable	Very Favorable
-3	-2	-1	0	1	2	3

SECTION 2.

In this section, you are asked to tell us your thoughts or feelings about external conditions that make it difficult to stick to safety rules. **Please circle the number that best describes your thoughts and feelings for each statement.**

Perceived Control

1. If I wanted to, I would not have any problems sticking to safety rules.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

2. To me, strictly complying with safety rules is easy.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

3. I have complete control over whether or not I follow the safety rules.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

SECTION 3.

Take a moment to think about your crew (by crew, we mean the group of people you work with as a team every day).

How many workers are in your crew?

In this section, we will ask about your feelings about your **crew** and **crew members**. **Please circle the number that best describes your thoughts and feelings for each statement.**

Feelings about Crew

1. I am similar to other members in my **crew**.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

2. Being a member of my **crew** is an important part of who I am.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

3. My self-image is overlapped with my **crew**'s image.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

4.I am happy to be a member of my **crew**.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

5. I feel strong sense of belonging to my **crew**.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

6. I like being a member of my **crew**.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

7. I am a valuable member of my **crew**.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

8. To me, being a member of my **crew** is an important source of self-esteem.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

9. I am an important member of my **crew**.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

Crew Members' Behavior

10. My **crew members** stop their work if they cannot find an anchor point to tie off when they are working on a surface 6 feet or more above the ground.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

11. My **crew members** always wear safety glasses when they are exposed to flying fragments and particles, even if safety glasses impede peripheral vision (e.g., fogging, scratching, and blurry lenses).

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

12. My **crew members** always connect their snap hook to an anchor point when they are working on a surface 6 feet or more above the ground, even if they do not perceive any danger of falling.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

13. My **crew members** do not take short cuts even if they are under time pressure.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

SECTION 4.

Take a moment to think about your project.

What is your project site?

In this section, we will ask about your feelings toward your **project** and **managers** in your project. Please circle the number that best describes your feelings for each statement.

Feelings about Project

1. I am similar to other members in this **project**.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

2. Being a member of this **project** is an important part of who I am.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

3. My self-image is overlapped with this **project's** image.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

4.I am happy to be a member of this **project**.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

5. I feel strong sense of belonging to this **project**.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

6. I like being a member of this **project**.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

7. I am a valuable member of this **project**.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

8. To me, being a member of this **project** is an important source of self-esteem.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

9. I am an important member of this **project**.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

Managers' Behavior

10. **Managers** on this project think that I should stop working if there is no anchor point to tie off when I am working on a surface 6 feet or more above the ground.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

11. **Managers** on this project think that I should always wear safety glasses when I am exposed to flying fragments and particles, even if safey glasses impede my vision (e.g., fogging, scratching, and blurry lenses).

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

12. **Managers** on this project think that I should always connect my snap hook to an anchor point when I am working on a surface 6 feet or more above the ground, even if it seems there is no danger of falling..

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

13. **Managers** on this project do not turn a blind eye to me taking a shortcut enven if I am under time pressure.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

SECTION 5.

Please circle the number that best describes your feelings for each statement.

Interpersonal-Orientation

1. It is important to me that I uphold my commitments to significant people in my life.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

2. Caring deeply about another person—such as a close friend or relative—is important to me.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

3. I value friends who are caring, empathetic individuals.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

Group- Orientation

4. Making a lasting contribution to groups that I belong to is very important to me.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

5. I feel great pride when my team or group does well, even if I am not the main reason for its success.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

6. When I am involved in a group project, I do my best to ensure its success.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

Willingness to Behavior

5. I intend to stop my work if I cannot find an anchor point to tie off when I am working a surface 6 feet or above the ground.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

6. I intend to wear safety glasses when I am exposed to flying fragments and particles, even if safety glasses impede my vision (e.g., fogging, scratching, and blurry lenses).

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

7. I intend to always connect my snap hook to an anchor point when I am working on a surface 6 feet or more above the ground, even if I do not perceive any danger of falling

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

8. I intend not to take any shortcut even if I am under the time pressure.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

Gender	Birth Year	Trade	Nationality
Are you foreman?	**Job experience**	**How long have you been working at this site?**	
Yes / No	years	months	

THANK YOU SO MUCH FOR YOUR PARTICIPATION.

WE APPRECIATE IT.

Construction Crew Survey

This survey is the second part of our study. If you participated in our previous survey, please read each question carefully and answer it to the best of your ability. Your honest responses will be highly valuable to our research.

SECTION 6.

Please circle the number that best describe your feelings for each statement.

Behavior

1. I always conncet my snap hook to an anchor point when I am working on surfaces 6 feet or more above the ground.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

2. I always wear safety glasses when I am exposed to flying fragments and particles.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

3. I do not take any short cut even if I am under time pressure.

Strongly Disagree	Disagree	Somewhat Disagree	Neither Disagree nor Agree	Somewhat Agree	Agree	Strongly Agree
-3	-2	-1	0	1	2	3

THANK YOU SO MUCH FOR YOUR PARTICIPATION.

APPENDIX C – Source Code for Agent-Based Model

```
# coding: utf-8

# In[9]:

# get_ipython().magic('matplotlib inline')

# Standard imports
import copy
import itertools

# Scientific computing imports
import numpy as np
import random
import matplotlib.pyplot as plt
import networkx
import pandas as pd
import seaborn; seaborn.set()
import statsmodels.formula.api as sm
from mpl_toolkits.mplot3d import Axes3D
from matplotlib import cm

# Import widget methods
from ipywidgets import *


# In[10]:

class Worker (object):
    """
        Worker class encapsulate the socio-cognitive process of worker's safety behavior
    """
    def __init__(self, model, worker_id, crew_type, p_unsafe_condition, risk_perception_coeff,
attitude_change, perceived_workgroup_norm, memory_capa, perceived_management_norm, min_risk_acceptance,
max_risk_acceptance, error_rate, weight_social,risk_attitude, project_identity):

        self.model = model
        self.worker_id = worker_id
        self.crew_type = crew_type
        self.p_unsafe_condition = p_unsafe_condition
```

```
        self.actual_risk = 0

        self.risk_perception_coeff = risk_perception_coeff
        self.attitude_change = attitude_change
        self.perceived_workgroup_norm = perceived_workgroup_norm
        self.memory_capa = memory_capa
        self.perceived_management_norm = perceived_management_norm
        self.perceived_manager_risk_acceptance = perceived_management_norm
        self.max_risk_acceptance = max_risk_acceptance
        self.min_risk_acceptance = min_risk_acceptance
        self.weight_social = weight_social
        self.risk_attitude = risk_attitude
        self.project_identity = project_identity

        self.error_rate = error_rate

        self.risk_acceptance = np.random.uniform(min_risk_acceptance, max_risk_acceptance)
        self.near_miss = 0

        if np.random.uniform(0,1) > 0.5 :
            self.unsafe_behavior = 0
        else:
            self.unsafe_behavior = 1

        self.neighbor_list = []
        self.workgroup_behavior = []

        if np.random.uniform(0,1) < self.p_unsafe_condition :
            self.unsafe_condition = 1
        else:
            self.unsafe_condition = 0


    def hazard_detection (self):
        if np.random.uniform(0,1) < self.p_unsafe_condition :
            self.unsafe_condition = 1
        else:
            self.unsafe_condition = 0

    def perceiving_risk(self):
```

```
        # Risk perception coefficient is determined by changes in risk attitude
        self.risk_perception_coeff -= self.attitude_change

        # Perceived risk is a function of actual risk and risk perception coefficient
        self.perceived_risk = self.actual_risk * self.risk_perception_coeff

        # Perceived risk cannot be greater than 1.0
        if self.perceived_risk > 1.0 :
            self.perceived_risk = 1.0
        else:
            self.perceived_risk = self.perceived_risk

        return


    def perceiving_workgroup_norm (self):
        # If there were not coworkers near the worker, there will be no changes in the perceived workgroup
norm
        self.previous_perceievd_workgroup_norm = self.perceived_workgroup_norm
        if len(self.workgroup_behavior) == 0 :
            self.perceived_workgroup_norm = self.previous_perceievd_workgroup_norm
            # If not, workgroup norm is the weighted sum of previous workgroup norm and the perception of
the average of workgroup behaviors
        else:
            # Calculating the average of workgroup behaviors
            self.avgerage_workgroup_behavior = sum(self.workgroup_behavior)/len(self.workgroup_behavior)
            self.perceived_workgroup_norm = (1-1/self.memory_capa)*self.previous_perceievd_workgroup_norm +
(1/self.memory_capa) * self.avgerage_workgroup_behavior

        return


    def perceiving_management_norm (self):
        # Management norm is the weighted sum of previous management norm and the current perception of
managers' risk acceptance
        self.previous_perceievd_management_norm = self.perceived_management_norm
        self.perceived_management_norm = (1-1/self.memory_capa)*self.previous_perceievd_management_norm +
(1/self.memory_capa) * self.perceived_manager_risk_acceptance

        return
```

```
    def determining_risk_acceptance (self):
        # Risk acceptance is determined by risk attitude, workgroup norm, management norm, and project
identity
        if np.random.uniform(0,1) < self.model.r_square:
            self.risk_acceptance = (1-self.weight_social)*self.risk_attitude + self.weight_social *
(self.project_identity*self.perceived_management_norm +(1-
self.project_identity)*self.perceived_workgroup_norm)
        else:
            # If the randomly selected number is greater than r^2 in the regression analysis, risk
acceptance will be randomly determined
            self.risk_acceptance = np.random.uniform(self.min_risk_acceptance,self.max_risk_acceptance)


    def decision_making (self):
        # if perceived risk is greater than risk acceptance, the worker will perform a safe behavior
        if self.perceived_risk >= self.risk_acceptance :
            # There would be some mistakes in executing safe behaviors
            if np.random.uniform(0,1) < self.error_rate :
                self.unsafe_behavior = 1
            else:
                self.unsafe_behavior = 0
        else:
            self.unsafe_behavior = 1

        return


    def receiving_manager_feedback (self):
        # If the worker performs a safe behavior, there will be no feedback from manager
        if self.unsafe_behavior == 0 :
            self.manager_feedback = 0
        else:
            # There might be some chances the worker will not receive feedback even if the worker performs
an unsafe behavior
            if np.random.uniform(0,1) < self.model.feedback_frequency :
                if self.actual_risk > np.random.uniform(self.model.min_manager_standard,
self.model.max_manager_standard):
                    self.manager_feedback = 1
                else:
                    self.manager_feedback = 0
```

```python
            else:
                self.manager_feedback = 0

        return


    def updating_manager_standard (self):
        # If the worker performs a safe behavior, there will be no changes in perceived managers' risk
acceptance
        if self.unsafe_behavior == 0 :
            self.perceived_manager_risk_acceptance = self.perceived_manager_risk_acceptance
        else:
            # If the worker receives feedback from managers, perceived managers' risk acceptance will
become lower than the current perceived risk
            if self.manager_feedback == 1 :
                self.perceived_manager_risk_acceptance = np.random.uniform(0, self.perceived_risk)

            #If the worker does not receive feedback from managers, perceived managers' risk acceptance
will become higher than the current perceived risk
            else:
                self.perceived_manager_risk_acceptance = np.random.uniform(self.perceived_risk, 1)


    def near_miss_occurrence (self):
        # If the worker performs an unsafe behavior, there is some possibilities of the near miss
        if self.unsafe_behavior == 1 or self.unsafe_behavior == 2:

            if np.random.uniform (0,1) < self.model.near_miss_occurence_coeff*self.actual_risk :
                self.near_miss = 1
            else:
                self.near_miss = 0
        # If the worker performs a safe behavior, there will be no near miss
        else :
            self.near_miss = 0


    def updating_risk_attitude (self):
        self.previous_risk_attitude = self.risk_attitude
        # If there is no near miss, the worker's risk attitude will be decreased.
        if self.unsafe_behavior == 1 :
            if self.near_miss == 0 :
```

```
                self.attitude_change = self.model.optimism_rate
            # If not, the worker's risk attitude will be increased.
            else:
                self.attitude_change = -self.model.arousal_rate
        else:
            self.attitude_change = 0
        self.risk_attitude = self.previous_risk_attitude + self.attitude_change


# In[11]:

class Model (object):
    """
    Model class, which encapsulates the entire behavior of single run of simulation model
    """
    def __init__(self, num_crews = 20, num_worker_per_crew = 10, ingroup_obs_ratio = 1.00,
outgroup_obs_ratio = 0.03, site_risk = 0.5, error_rate = 0.01, min_risk_perception_coeff = 0.6,
max_risk_perception_coeff = 1.2, min_perceived_workgroup_norm = 0.1, max_perceived_workgroup_norm = 0.9,
memory_capa = 15, min_perceived_management_norm = 0.1, max_perceived_management_norm = 0.9,
min_manager_standard = 0.2, max_manager_standard = 0.4, min_risk_acceptance = 0.1, max_risk_acceptance =
0.9, attitude_change = 0, r_square = 0.85, weight_social = 0.75, min_risk_attitude = 0.1, max_risk_attitude
= 0.9, min_project_identity = 0.1, max_project_identity = 0.9,feedback_frequency = 0.7,
near_miss_occurence_coeff = 0.01, arousal_rate = 0.20, optimism_rate = 0.001,):

        self.num_crews = num_crews
        self.num_worker_per_crew = num_worker_per_crew

        self.ingroup_obs_ratio = ingroup_obs_ratio
        self.outgroup_obs_ratio = outgroup_obs_ratio

        self.site_risk = site_risk
        self.error_rate =  error_rate
        self.min_risk_perception_coeff = min_risk_perception_coeff
        self.max_risk_perception_coeff = max_risk_perception_coeff
        self.min_perceived_workgroup_norm = min_perceived_workgroup_norm
        self.max_perceived_workgroup_norm = max_perceived_workgroup_norm
        self.min_perceived_management_norm = min_perceived_management_norm
        self.max_perceived_management_norm = max_perceived_management_norm
        self.memory_capa = memory_capa
        self.min_manager_standard = min_manager_standard
        self.max_manager_standard = max_manager_standard
```

```
        self.attitude_change = attitude_change
        self.weight_social = weight_social
        self.near_miss_occurence_coeff = near_miss_occurence_coeff

        self.min_risk_acceptance = min_risk_acceptance
        self.max_risk_acceptance = max_risk_acceptance
        self.min_risk_attitude = min_risk_attitude
        self.max_risk_attitude = max_risk_attitude

        self.min_project_identity = min_project_identity
        self.max_project_identity = max_project_identity

        self.r_square = r_square
        self.feedback_frequency = feedback_frequency
        self.arousal_rate = arousal_rate
        self.optimism_rate = optimism_rate

        self.t = 0
        self.worker = []

        # Set the history variables
        self.history_unsafe_behavior = []
        self.history_near_miss =[]
        self.history_risk_attitude = []
        self.history_perceived_risk = []
        self.history_risk_acceptance = []
        self.history_perceived_workgroup_norm = []
        self.history_perceived_management_norm = []
        self.history_incident_rate=[]
        self.history_unsafe_behavior_ratio = []

        self.setup_worker ()


    def setup_worker(self):
        """
        Method to set up workers in the model
        """
        for i in range(self.num_crews) :
            for j in range(self.num_worker_per_crew):
```

```
                self.worker.append(Worker(model = self, worker_id = j+i*self.num_worker_per_crew, crew_type
= i, p_unsafe_condition = self.site_risk, risk_perception_coeff =
np.random.uniform(self.min_risk_perception_coeff, self.max_risk_perception_coeff), perceived_workgroup_norm
= np.random.uniform(self.min_perceived_workgroup_norm, self.max_perceived_workgroup_norm), memory_capa =
self.memory_capa, perceived_management_norm = np.random.uniform(self.min_perceived_management_norm,
self.max_perceived_management_norm), min_risk_acceptance = self.min_risk_acceptance, max_risk_acceptance =
self.max_risk_acceptance, error_rate = self.error_rate, attitude_change = self.attitude_change,
weight_social = self.weight_social, risk_attitude = np.random.uniform(self.min_risk_attitude,
self.max_risk_attitude), project_identity = np.random.uniform(self.min_project_identity,
self.max_project_identity),))


    def get_worker_neighbors(self):
        for i in range(self.num_crews*self.num_worker_per_crew):
            # Before creating the neighbor list, deleting the previous list
            del self.worker[i].neighbor_list[0:len(self.worker[i].neighbor_list)]


            for j in range(self.num_crews*self.num_worker_per_crew):
                # Himself or herself cannot be a neighbor
                if j == self.worker[i].worker_id:
                    self.worker[i].neighbor_list = self.worker[i].neighbor_list

                else:
                    # If the j is the same workgroup member
                    if self.worker[j].crew_type == self.worker[i].crew_type:
                        if np.random.uniform(0,1) < self.ingroup_obs_ratio:
                            self.worker[i].neighbor_list.append(j)
                        else:
                            self.worker[i].neighbor_list == self.worker[i].neighbor_list
                    # If the j is not the same workgroup member
                    else:
                        if np.random.uniform(0,1) < self.outgroup_obs_ratio:
                            self.worker[i].neighbor_list.append(j)
                        else:
                            self.worker[i].neighbor_list = self.worker[i].neighbor_list


    def step_interact(self):
        """
```

```
        Interacting workers by observing coworkers' behaviors and receiving safety feedback from managers
and taking their safety behaviors based on the interaction
        """
        self.get_worker_neighbors()

        random_order = list(range(self.num_crews * self.num_worker_per_crew))
        np.random.shuffle(random_order)

        for i in random_order:

            self.worker[i].actual_risk = random.betavariate(5 * self.site_risk, 5-5*self.site_risk)
            self.worker[i].hazard_detection()

            # If a worker is in a safe condition, the worker will not perform an unsafe behavior
            if self.worker[i].unsafe_condition == 0:
                # There are some errors even in a safe condition
                if np.random.uniform(0,1) < self.error_rate:
                    self.worker[i].unsafe_behavior = 2 #mistakes
                    self.worker[i].near_miss_occurrence()
                    if self.worker[i].near_miss == 1:
                        self.worker[i].attitude_change = -self.arousal_rate
                    else:
                        self.worker[i].attitude_change = 0
                    self.worker[i].risk_attitude += self.worker[i].attitude_change

                else:
                    self.worker[i].unsafe_behavior = 0
                    self.worker[i].near_miss_occurrence()
                    self.worker[i].attitude_change = 0
                    self.worker[i].risk_attitude += self.worker[i].attitude_change

            # If a worker is in an unsafe condition the safety decision-making process will be started
            else:
                self.worker[i].perceiving_risk()

                del self.worker[i].workgroup_behavior[0:len(self.worker[i].workgroup_behavior)]

                # The worker will observe the neighbors' behavior to determine risk acceptance
                for j in self.worker[i].neighbor_list:

                    if self.worker[j].unsafe_condition == 1:
```

```
                        # If the neighbor performs a safe behavior, the observed behavior will be between 0 
and neighbor's actual risk.
                        if self.worker[j].unsafe_behavior == 0:
                            observation = np.random.uniform(0, self.worker[j].actual_risk)
                        # If the neighbor performs an unsafe behavior, the observed behavior will be 
between neighbor's actual risk and 1.
                        elif self.worker[j].unsafe_behavior == 1:
                            observation = np.random.uniform(self.worker[j].actual_risk, 1)
                            self.worker[i].workgroup_behavior.append(observation)
                        else:
                            print ("error")
                    # If the worker is under a safe condition, the worker  will not observe the neighbors
                    else:
                        self.worker[i].workgroup_behavior = self.worker[i].workgroup_behavior

                self.worker[i].perceiving_workgroup_norm()
                self.worker[i].perceiving_management_norm()
                self.worker[i].determining_risk_acceptance()
                self.worker[i].decision_making()
                self.worker[i].receiving_manager_feedback()
                self.worker[i].updating_manager_standard()
                self.worker[i].near_miss_occurrence()
                self.worker[i].updating_risk_attitude()


    def get_avg_unsafe_behavior(self):
        total = 0
        for worker in self.worker:
            if worker.unsafe_behavior == 1 or worker.unsafe_behavior == 2:
                total+= 1
            else:
                total = total
        return total / len(self.worker)


    def get_near_miss(self):
        total = 0
        for worker in self.worker:
            total +=  worker.near_miss
        return total
```

```
def get_avg_risk_attitude(self):
    total = 0
    for worker in self.worker:
        total +=  worker.risk_attitude
    return total / len(self.worker)


def get_avg_perceived_workgroup_norm(self):
    total = 0
    for worker in self.worker:
        total += worker.perceived_workgroup_norm
    return total / len(self.worker)


def get_avg_perceived_management_norm(self):
    total = 0
    for worker in self.worker:
        total += worker.perceived_management_norm
    return total / len(self.worker)


def get_avg_risk_acceptance (self):
    total = 0
    for worker in self.worker:
        total += worker.risk_acceptance
    return total / len(self.worker)


def get_incident_rate(self):
    total_near_miss = sum(self.history_near_miss)
    total_working_hour = (self.t)*self.num_crews*self.num_worker_per_crew*8
    return total_near_miss/total_working_hour*200000/10


def get_unsafe_behavior_ratio (self):
    total_unsafe_condition  = 0
    total_unsafe_behavior = 0
    for worker in self.worker:
        total_unsafe_condition += worker.unsafe_condition
        if worker.unsafe_behavior == 1:
```

```
                total_unsafe_behavior += 1
            else:
                total_unsafe_behavior = total_unsafe_behavior

        return total_unsafe_behavior/total_unsafe_condition


    def step(self):
        self.step_interact()
        self.t = self.t+1
        self.history_unsafe_behavior.append(self.get_avg_unsafe_behavior())
        self.history_near_miss.append(self.get_near_miss())
        self.history_risk_attitude.append(self.get_avg_risk_attitude())
        self.history_perceived_workgroup_norm.append(self.get_avg_perceived_workgroup_norm())
        self.history_perceived_management_norm.append(self.get_avg_perceived_management_norm())
        self.history_risk_acceptance.append(self.get_avg_risk_acceptance())
        self.history_incident_rate.append(self.get_incident_rate())
        self.history_unsafe_behavior_ratio.append(self.get_unsafe_behavior_ratio())

        return
```

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